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Empirical analysis of economic growth

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Abstract

International evidence on growth rates in per capita incomes reveals persistent differences in economic growth and development patterns among nations, and shows that the world distribution of per capita income is multi-modal with several basins of attraction. This dissertation investigates the factors underlying these international variations in both the level and rate of growth of per capita incomes.

The first essay examines whether nonlinearities in the aggregate production function can explain parameter heterogeneity in the Solow (1956) growth regressions. The choice of an alternative specification of the production function is justified by showing that cross-country level regressions are more consistent with the more general Constant Elasticity of Substitution (CES) than the Cobb-Douglas technology which currently underlies the Solow model. Then, by using an endogenous threshold methodology, we find that the Solow model, using the nonlinear CES technology, implies more robust parameter heterogeneity that is consistent with the existence of multiple regimes.

The second essay uses Bayesian Model Averaging methodology to ascertain whether the determinants of economic growth are the same in Africa as elsewhere. Specifically, we estimate the posterior probability of a number of possible explanatory variables and potential cross-country regression models. We find that in both the short and long run, determinants of growth in Africa are different from the rest of the world. In addition, our findings suggest that in contrast to the rest of the world, initial conditions and economic institutional variables are more important in explaining African growth than policy and political institutional variables.

The third essay investigates the role of initial conditions as threshold variables in economic development. Using the endogenous threshold methodology, we test whether initial stocks of human capital, initial level of economic development and natural conditions do affect long run growth in per capita incomes. We get two principal results. First, initial stocks of human capital and the initial level of economic development have lasting effects on long run growth in per capita incomes. Second, initial conditions reflecting natural conditions have no lasting effect on economic growth.

Chapter 1

Introduction

In the past 40 years a startling pattern has emerged from the international evidence on economic growth and development. The international evidence on growth rates of per capita incomes reveals persistent differences in development patterns among nations. While some countries manage to sustain high growth rates over long periods of time, others have stagnated in low growth traps. There is now a growing realization that rather than converging to some common steady state, the world distribution of per capita income is actually thinning in the middle (Azariadis, 1996). Unfortunately, this realization runs counter to predictions of conventional growth models. However, in light of the divergence between the evidence and predictions of growth models, it is imperative to question the assumptions underlying conventional growth models since their failure to establish reliable results in the analysis of cross-country growth behavior has rendered them both statistically misspecified and certainly theoretically uncompelling (Kourtellos, 2001).

This PhD thesis is a combination of three essays which empirically test postulations of standard growth models. It attempts to investigate the following: (i) the role of the specification of the production function in explaining cross-country variations in the level and growth rates of per capita income; (ii) whether determinants of growth in Africa are the same as elsewhere; (iii) the role of initial conditions in affecting long run growth in per capita output.

The first essay, *Solow Model with CES Technology*, proposes a nonlinear specification of the production function for modelling coefficient heterogeneity and nonlinearities in the basic and extended Solow growth models. Standard Solow-type growth models make two simplifying assumptions. First, they assume parameter homogeneity. That is, coefficients of cross-country growth regressions are assumed to be country-invariant, so that international variations in standards of living can be explained using a common specification of the production function for all nations. Second, they assume a linear relationship between the growth rate of output and its determinants.

This essay questions these two assumptions. These questions are motivated by recent papers by Brock and Durlauf (2000) and Durlauf (2001) who argue that the basic Solow (1956) model and conventional cross-country linear regression models, a *là* Mankiw, Romer and Weil (1992) impose strong homogeneity assumptions on the growth process. This is especially crucial because there is nothing in the theoretical and empirical literature to suggest that all countries obey a common linear production function. Certainly, the theoretical growth literature does not suggest that the effect of a change in a particular variable (such as education or the savings rate) on economic growth is, or should be, the same across countries. In the words of Brock and Durlauf "... the assumption of parameter homogeneity seems particularly inappropriate when one is studying complex heterogenous objects such as countries."

This essay builds on a number of empirical studies, including Durlauf and Johnson (1995), Liu and Stengos (1999), Durlauf, Kourtellos and Minkin (2001), Kalaitzidakis et al. (2001) and Kourtellos (2001) who find strong evidence in favor of *parameter heterogeneity* notwithstanding their different methodological approaches. However, accepting the notion of parameter heterogeneity in growth regressions raises more questions than it resolves because there is little consensus regarding both the meaning and sources of parameter heterogeneity. The literature offers at least three possible interpretations: First, are growth process nonlinearities: multiple steady-state models such as Azariadis and Drazen (1990), Durlauf (1993) and Galor and Zeira (1993) suggest that parameters of a linear growth regression will not be constant across countries. Put differently, in a cross-country growth regression, countries are characterized by different coefficient estimates. Second, omitted growth determinants: recent models show that introduction of new variables in the standard Solow growth model may induce nonlinearities resulting in multiple steady states and poverty traps (Durlauf and Quah (1999) enumerate a large number of such variables). Third, nonlinearity of the production function: the identical Cobb-Douglas aggregate production technology – a necessary condition for the linearity of the Solow growth model – assumed in the vast majority of existing studies may be inappropriate.

Specifically, this essay investigates the third interpretation – whether nonlinearities in the aggregate production function can explain parameter heterogeneity in growth regressions. Since most theoretical implications about growth are based on the Solow-type growth models, this essay investigates if the qualitative implications of the Solow model change when we change the specification of the production function. In addition, does the specification of the production function affect how countries are classified into membership of convergence clubs?

We first test whether the data bear out the commonly used Cobb-Douglas (CD) specification or a more general specification. Having established that international growth evidence is consistent with the more general specification, we replace the CD with the more general Constant-Elasticity-of-Substitution (CES) aggregate production specification in the Solow growth model. While there are flexible functional forms for the specification of the production function, our choice of the CES specification was motivated by both theoretical and empirical evidence. Duffy and Papageorgiou (2000) find empirical support in favor of a more general CES specification of the aggregate input–output production relationship. Similarly, theoretical contributions, such as Ventura (1997), Klump and de La Grandville (2000), Azariadis (2001) and Azariadis and de la Croix (2001), show that since the elasticity of substitution between inputs may play an important role in the growth process we need a functional form which allows for changes in the elasticity of substitution.

We derive the equivalent of the basic and extended Solow growth model with CES technology and test whether this functional form eliminates the parameter heterogeneity observed in the CD-based Solow models. We find that, unlike the Solow models with CD, the Solow model with CES results in more regimes. In other words, of the three explanation of parameter heterogeneity, we can eliminate the nonlinearity of the production function as a possible explanation.

The second essay, *Determinants of Economic Growth in Africa*, investigates factors underlying Africa's slow economic growth. The international growth evidence clearly shows that African nations dominate the group of slow growing economies and comprise the bulk of less developed nations. In addition, although international development agencies assert that generating sustained economic growth in Sub-Saharan Africa remains the most pressing challenge to global development (Block, 2001), little is known about the determinants of economic growth in Africa.

Two positions characterize the debate on African growth and development. On the one hand, Africa's slow growth has traditionally been explained in terms of the peculiarity of its geography, a preponderance of poor policies and lack of institutions that are conducive to economic growth (Landes, 1998; Collier and Gunning, 1999). However, a number of studies explicitly argue that determinants of growth in Africa are the same as elsewhere, so that Africa's slow growth should be explained in terms of lower mean levels of globally relevant growth enhancing factors and relatively higher levels of growth retarding factors (Barro, 1991; Easterly and Levine, 1999; Sachs and Warner, 1995, 1997). Consequently, informed opinion is sharply divided on whether Africa grows differently to warrant an Africa-only theory of growth or whether African economic development can be explained within the global context.

However, among those who hold that African growth can be explained within the global context, there are disagreements regarding variables that are critical for explaning African growth. Sachs and Warner (1997) contend that Africa can be distinguished due to its unique geographical and environmental characteristics. However, Easterly and Levine (1999, 2001) argue that geography notwithstanding, Africa's slow growth is a reflection of poor institutional infrastructure. On their part, the World Bank and other international organizations maintain that the effects of geography and institutions can be overcome with good policies. Therefore, Africa's growth is primarily a reflection of its poor policy choices. Unfortunately, this divergence of views about the relevance and importance of different variables is equally matched by a lack of guidance from economic theory regarding which variables to include in growth regressions.

This essay explicitly investigates the determinants of economic growth in Africa using a Bayesian model averaging framework following Fernandez, Ley and Steel (2001). This framework allows us to do two novel things which hitherto were impossible to implement. First, to investigate the issue of model uncertainty in African growth regressions by estimating the posterior probabilities of many possible explanatory variables commonly used in cross-country growth regressions for which data are available. Second, we attempt to identify the factors explaining differences in growth by allowing for any subset of these variables to combine in a growth regression and estimate the implied posterior probability of any such combination of regressors. This work contributes to the growth literature in two ways. First, by comparing the posterior probability of different variables in the global and Africa-only sample, we explicitly test whether Africa grows differently. Second, based on formal statistical inference, we can show which combination of variables best explains cross-country growth in Africa.

The third essay, *Initial Conditions as Threshold Variables in Economic Development,* investigates the role of initial conditions in economic growth. As earlier indicated, standard economic growth models have the counterfactual implication that nations with identical economic structures would converge to the same steady state or balanced growth path. The implication is that absent differences in initial conditions, not only will nations which share common fundamentals and are structurally identical converge to the same steady state, but also that poor economies which were initially lacking in efficient production techniques, should grow faster and eventually catch up with developed economies as production techniques diffuse from the developed to developing nations. This essay is motivated by the realization that contrary to predictions of conventional growth models, growth rates in per capita incomes are actually diverging, resulting in differences in development patterns among nations, including otherwise structurally identical economies.

The economics literature gives any number of possible explanations for these persistent cross-country differences in economic growth. One strand of theoretical explanation maintains that "cross-country growth would be fundamentally the same except for differences in history, e.g. in the circumstances from which the growth process begins" Azariadis (1996: p.452). This literature has especially focused on the role of initial stocks of human and physical capital and the state of technology in achieving sustainable economic growth. In other words, given two structurally identical economies, depending on their history and differences in initial conditions, one country with certain initial conditions below some threshold will stagnate and never be able to go above the "growth hump" while the other, due to its different history can achieve sustainable growth.

This essay seeks to empirically investigate this view by specifically examining the extent to which natural and initial conditions preserve and augment initial inequality in per capita incomes among otherwise identical national economies. This issue is especially important because the issue of whether per capita income levels in countries are converging or not hinges on the role of initial conditions on long run development. If initial conditions are irrelevant in the long run, then income levels will converge globally after controlling for any pertinent microeconomic heterogeneity. However, if initial conditions are important then they can create history-dependent growth paths which in turn result in history-dependent development. This work draws on work by Durlauf and Johnson (1995) and Hansen (2001) who find support for the role of initial output and initial adult literacy rates in a cross section of countries and Johnson and Takeyama (2001) who find threshold effects for the density of initial capital stock among the 48 contiguous US states.

We address these issues using the endogenous threshold methodology of Hansen (2001) who develops a statitistical theory for testing for threshold effects of any variable in a cross-sectional setting. This methodology allows us to do two things. First, test if a particular variable can be used to split the sample of countries. Second, for those variables with significant threshold effects we can estimate the implied threshold and derive the associated confidence intervals. This enables us to classify countries on the basis of their growth rates but with reference to some thresholds given by initial conditions.

This essay demonstrates two things. First, we confirm earlier studies which found that initial conditions have lasting effects on long run growth. In fact we show that alternative measures of the initial stock of human capital or economic development lead to similar thresholds and international convergence regimes. Second, we demonstrate that geography is not destiny. None of the initial conditions representing geography exhibits any first-level threshold effects.

Chapter 2

Solow Model with CES Technology

2.1 Introduction

Recent papers by Brock and Durlauf (2000) and Durlauf (2001) argue that the conventional Mankiw, Romer and Weil (1992) (MRW hereafter) cross-country linear regression model based on Solow (1956) imposes strong homogeneity assumptions on the growth process. Assuming *parameter homogeneity* in growth regressions is equivalent to assuming that all countries have an identical Cobb-Douglas (CD) aggregate production function. This is clearly an implausible assumption as there is nothing in the empirical or theoretical growth literature to suggest that the effect of a change in a particular variable (such as education or the savings rate) on economic growth is the same across countries. In the words of Brock and Durlauf "... the assumption of parameter homogeneity seems particularly inappropriate when one is studying complex heterogenous objects such as countries."

Not surprisingly, several empirical studies including Durlauf and Johnson (1995), Liu and Stengos (1999), Durlauf, Kourtellos and Minkin (2001), Kalaitzidakis et al. (2001) and Kourtellos (2001) find strong evidence is favor of *parameter heterogeneity* notwithstanding their different methodological approaches. Parameter heterogeneity in growth regressions has at least three possible interpretations: (a) Growth process nonlinearities: Multiple steady-state models such as Azariadis and Drazen (1990), Durlauf (1993) and Galor and Zeira (1993) suggest that parameters of a linear growth regression will not be constant across countries. Put differently, in a cross-country growth regression, countries are characterized by different coefficient estimates. (b) Omitted growth determinants: Recent models show that introduction of new variables in the standard Solow growth model may induce nonlinearities resulting in multiple steady states and poverty traps (Durlauf and Quah (1999) enumerate a large number of such variables). (c) Nonlinearity of the production function: The identical CD aggregate production technology – a necessary condition for the linearity of the Solow growth model – assumed in the vast majority of existing studies maybe inappropriate.

This paper investigates interpretation (c) – whether nonlinearities in the aggregate production function can explain parameter heterogeneity in growth regressions. In particular, we replace the CD with the more general Constant-Elasticity-of-Substitution (CES) aggregate production specification in the Solow growth model.[1] Our choice of the CES (nonlinear) specification is motivated, in part, by Duffy and Papageorgiou (2000) who find empirical support in favor of a more general CES specification of the aggregate input–output production relationship where the elasticity of substitution between capital and labor (or effective labor) is significantly greater than unity.[2] Our choice of production technology is also motivated by recent theoretical contributions, such as Ventura (1997), Klump and de La Grandville (2000), Azariadis (2001) and Azariadis and de la Croix (2001), which show that the elasticity of substitution between inputs may play an important role in the growth process.

In this paper, we first justify our choice of the production function by showing that in the context of MRW cross-country level regressions, we can reject the CD in favor of the more general CES aggregate production specification. This is

[1]Although Solow (1957) was the first to suggest the use of the CD specification to characterize aggregate production, he also noted that there was little evidence to support the choice of such a specification. In fact, in his seminal 1956 paper, Solow presented the CES production function as one example of technologies for modeling sustainable economic growth.

[2]Duffy and Papageorgiou (2000) employ linear and nonlinear panel estimation techniques and data on 82 countries over 28 years to estimate a CES aggregate production function specification.

an important result given that the CD is a necessary condition for the linearity of the Solow growth model. Then, by using the endogenous threshold methodology of Hansen (2000) we show that the Solow model with CES production technology implies robust non-linearities in the growth process that are consistent with parameter heterogeneity and the existence of multiple regimes. This last result suggests that using the CES aggregate production function (which is found to be empirically favorable to CD) in growth regressions does not explain away (and if anything amplifies) heterogeneity across countries, therefore shifting attention to the other two alternative interpretations mentioned above.

The rest of the paper is organized as follows. Section 2 derives the regression equations from the Solow model under CD and CES production technologies. Section 3 presents and discusses the results obtained from estimating these regressions. Section 4 employs the Hansen (2000) endogenous threshold methodology to examine the possibility of multiple regimes. Section 5 summarizes and concludes.

2.2 Solow Model with CES Technology

We start by revisiting the Solow growth model with CD specification. We then replace the CD with the more general CES technology and derive the regression equations which will be estimated later on.

2.2.1 The Basic and Extended Solow-CD Models

MRW start their cross-country empirical investigation by using the basic Solow growth model where aggregate output in country i (Y_i) is determined by a CD production function, taking as arguments the stock of physical capital (K_i) and technology-augmented labor (AL_i), according to

$$Y_i = K_i^{\alpha}(AL_i)^{1-\alpha},$$

where $\alpha \in (0,1)$ is the share of capital, and A and L grow exogenously at rates g and n, respectively. Each country accumulates physical capital according to the motion equation $dK_i/dt = s_{ik}Y_i - \delta K_i$, where s_{ik} is the savings rate and δ is the depreciation rate of capital. After solving for the steady-state output per unit of augmented labor (y_i), log-linearizing and imposing the cross-coefficient restrictions on α, they obtain the *basic Solow-CD equation*

$$\ln\left(\frac{Y_i}{L_i}\right) = \ln A(0) + gt + \frac{\alpha}{1-\alpha}\ln\left(\frac{s_{ik}}{n_i+g+\delta}\right). \tag{2.1}$$

MRW's implied estimate of the capital share α was implausibly high relative to the capital share in national income thus motivating these authors to extend their basic model by introducing human capital (H_i) as an additional factor of production. Output in the extended model is determined by a CD production function of the form

$$Y_i = K_i^{\alpha} H_i^{\beta} (AL_i)^{1-\alpha-\beta},$$

where $\alpha \in (0,1)$ is the share of physical capital and $\beta \in (0,1)$ is the share of human capital. Physical and human capital accumulation equations take the form $dK_i/dt = s_{ik}Y_i - \delta K_i$, and $dH_i/dt = s_{ih}Y_i - \delta H_i$ respectively, where s_{ik} is the fraction of income invested in physical capital, s_{ih} is the fraction invested in human capital and δ is a common depreciation rate. Once again, solving for the steady-state output per unit of augmented labor, log-linearizing and imposing the cross-coefficient restrictions on α and β they obtain the *extended Solow-CD equation*[3]

$$\ln\left(\frac{Y_i}{L_i}\right) = \ln A(0) + gt + \frac{\alpha}{1-\alpha-\beta}\ln\left(\frac{s_{ik}}{n_i+g+\delta}\right) + \frac{\beta}{1-\alpha-\beta}\ln\left(\frac{s_{ih}}{n_i+g+\delta}\right). \tag{2.2}$$

[3]The cross-coefficient restrictions require that the coefficient on $\ln(n_i+g+\delta)$ is equal in magnitude and opposite in sign to the coefficient on $\ln s_{ik}$ in the basic Solow regressions (equal in magnitude and opposite in sign to the sum of the coefficients on $\ln s_{ik}$ and $\ln s_{ih}$ in the extended Solow regressions).

2.2.2 The Basic and Extended Solow-CES Models

Next, we replace the CD with the more general CES aggregate production specification in the Solow growth model. The production function becomes

$$Y_i = \left[\alpha K_i^{\frac{\sigma-1}{\sigma}} + (1-\alpha)(AL_i)^{\frac{\sigma-1}{\sigma}}\right]^{\frac{\sigma}{\sigma-1}},$$

where $\alpha \in (0,1)$ is now what Arrow et al. (1961) called the "distribution parameter" (rather than the share) of physical capital, and $\sigma \geq 0$ is the elasticity of substitution between capital and technology-augmented labor. It is well-known that when $\sigma = 1$ the CES production function reduces to the CD case. Assuming that the evolution of capital is governed by the same motion equation as in MRW, we derive the steady-state output per augmented labor as

$$y_i^* = \left[\frac{1}{1-\alpha} - \frac{\alpha}{1-\alpha}\left(\frac{s_{ik}}{n_i+g+\delta}\right)^{\frac{\sigma-1}{\sigma}}\right]^{-\frac{\sigma}{\sigma-1}}. \tag{2.3}$$

Taking logs and linearizing using a second order Taylor series expansion around $\sigma = 1$, as in Kmenta (1967), we obtain the *basic Solow-CES equation*[4]

$$\ln\left(\frac{Y_i}{L_i}\right) = \ln A\,(0) + gt + \frac{\alpha}{1-\alpha}\ln\left(\frac{s_{ik}}{n_i+g+\delta}\right) + \frac{1}{2}\frac{\sigma-1}{\sigma}\frac{\alpha}{(1-\alpha)^2}\left[\ln\left(\frac{s_{ik}}{n_i+g+\delta}\right)\right]^2. \tag{2.4}$$

There are several points worth making here. The second order linear approximation of the CES function given by equation (2.4) consists of two additively separable terms: The linear term $\ln A\,(0) + gt + \frac{\alpha}{1-\alpha}\ln\left(\frac{s_{ik}}{n_i+g+\delta}\right)$ is the first order linear approximation of the CES function that corresponds to the CD function, and the quadratic term $\frac{1}{2}\frac{\sigma-1}{\sigma}\frac{\alpha}{(1-\alpha)^2}\left[\ln\left(\frac{s_{ik}}{n_i+g+\delta}\right)\right]^2$ corresponds to a correction due to the departure of σ from unity. Our linear approximation, around $\sigma = 1$, of the CES production technology provides the CD specification with its *best opportunity* to characterize the cross-country output per worker relationship. Notice that if $\sigma = 1$ (i.e. the CD case) then the last term vanishes so that equation (2.4) is reduced to the *basic*

[4]See Appendix B for derivation of equations (2.3-2.4).

Solow-CD equation (2.1). More importantly, notice that if σ is significantly different from unity it implies that the basic Solow-CD linear equation is mispecified. The potential specification error is associated with the choice of production function and is captured by the quadratic term of equation (2.4). The magnitude of the specification error depends on the extent to which σ departs from unity.

Next, we incorporate human capital in the CES aggregate production function as follows:

$$Y_i = \left[\alpha K_i^{\frac{\sigma-1}{\sigma}} + \beta H_i^{\frac{\sigma-1}{\sigma}} + (1-\alpha-\beta)(AL_i)^{\frac{\sigma-1}{\sigma}}\right]^{\frac{\sigma}{\sigma-1}},$$

where α and β are distribution parameters, H is the stock of human capital and σ is the elasticity of substitution between any two factors of production ($\sigma = \sigma_{j,k}$ for $j \neq k$, where $j,k = K,\ H,\ AL$).[5] Assuming the same motion equations for physical and human capital as in the *extended Solow-CD model*, we derive the steady state output per augmented labor as

$$y_i^* = \left[\frac{1}{1-\alpha-\beta} - \frac{\alpha}{1-\alpha-\beta}\left(\frac{s_{ik}}{n_i+g+\delta}\right)^{\frac{\sigma-1}{\sigma}} - \frac{\beta}{1-\alpha-\beta}\left(\frac{s_{ih}}{n_i+g+\delta}\right)^{\frac{\sigma-1}{\sigma}}\right]^{-\frac{\sigma}{\sigma-1}}. \tag{2.5}$$

A second order linearization of equation (2.5) around $\sigma = 1$ yields the *extended Solow-CES equation*[6]

$$\begin{aligned} \ln\left(\frac{Y_i}{L_i}\right) &= \ln A(0) + gt + \tfrac{\alpha}{1-\alpha-\beta}\ln\left(\tfrac{s_{ik}}{n_i+g+\delta}\right) + \tfrac{\beta}{1-\alpha-\beta}\ln\left(\tfrac{s_{ih}}{n_i+g+\delta}\right) \\ &\quad + \tfrac{1}{2}\tfrac{\sigma-1}{\sigma}\tfrac{1}{(1-\alpha-\beta)^2}\left\{\alpha\left[\ln\left(\tfrac{s_{ik}}{n_i+g+\delta}\right)\right]^2 + \beta\left[\ln\left(\tfrac{s_{ih}}{n_i+g+\delta}\right)\right]^2\right\} \\ &\quad - \tfrac{1}{2}\tfrac{\sigma-1}{\sigma}\tfrac{1}{(1-\alpha-\beta)^2}\left\{\alpha\beta\left[\ln\left(\tfrac{s_{ik}}{s_{ih}}\right)\right]^2\right\}. \end{aligned} \tag{2.6}$$

[5] In the three-factor case there is no "traditional" definition of the elasticity of substitution. Here we use the *Allen Partial Elasticity of Substitution* (APES) (see Allen 1938, pp.503-509) which asserts that if the production function is of the form $f(x_1,...,x_n) = \left[a_1 x_1^{\frac{\sigma-1}{\sigma}},...,a_n x_n^{\frac{\sigma-1}{\sigma}}\right]^{\frac{\sigma}{\sigma-1}}$ then $\sigma = \sigma_{j,k}$ for all $j \neq k$, where $j,k = 1,...,n$. For an extensive discussion on the properties of APES see Uzawa (1962).

[6] See Appendix B for the derivation of equations (2.5-2.6).

One can easily verify that by eliminating human capital accumulation ($\beta = 0$), equation (2.6) reduces to the *basic Solow-CES equation* (2.4). It is also easy to verify that in the special case of unitary elasticity of substitution ($\sigma = 1$), equation (2.6) reduces to the *extended Solow-CD equation* (2.2).

2.3 Data, Estimation and Results

The baseline dataset employed in our estimation is identical to that of MRW (PWT version 4.0), and our discussion focuses on the non-oil sample which includes 98 countries. The variables used in our baseline estimation are: per capita output in 1985 ($\frac{Y_i}{L_i}$), the ratio of average investment to GDP over the 1960-1985 period (s_{ik}), the average percentage of working age population (population between the age of 15 and 64) in secondary education over the period 1960-1985 (s_{ih}), and the average working age population growth rate from 1960-1985 (n_i). Following MRW we assume that $g + \delta = 0.05$. As a robustness check of our baseline results we will also use the updated PWT version 6.0 which extends the coverage to 1995 for a subsample of 90 countries.[7,8]

To establish the specification of the aggregate production function consistent with the data we first test whether the estimated coefficients associated with the quadratic terms are statistically significant and then test whether the implied elasticity of substitution parameter σ is statistically different from unity. Our estimation considers linear and nonlinear least-squares regressions to obtain parameter estimates for the *basic* and *extended Solow models.* Tables 2.1-2.2 present estimated coefficients for each of the four regression equations (2.1), (2.2), (2.4) and (2.6). The upper panels of Tables 2.1-2.2 present results from the "unrestricted" models (without cross-coefficient restrictions) while the lower panels present the implied coefficient

[7] For detailed explanation of the data see Bernanke and Gürkaynak (2001, pp.8-9). The data are available on-line at http://www.princeton.edu/~gurkaynk/growthdata.html.

[8] The countries with missing observations in PWT version 6.0 are Burma, Chad, Germany, Haiti, Liberia, Sierra Leone, Somalia, and Sudan.

estimates for α, β and σ from the "restricted" models (with cross-coefficient restrictions).

2.3.1 Basic Solow Regression Results

Table 1 presents estimates for the *basic* and *extended Solow-CD* and *-CES models* using the PWT 4.0 dataset. Columns 2 and 4 replicate the MRW results for the *basic* and *extended Solow-CD models* whereas columns 3 and 5 extend these results to the CES models.

First, we compare the regression results of the *basic Solow-CD* and *-CES models* (reported in columns 2 and 3 of Table 2.1). In terms of the overall fit, we find that the CD model can explain 59% whereas the CES model can explain 60% of the overall variation in per capita income. Replacing the CD with the more general CES specification does not affect the predicted signs of the coefficients, but it reduces their magnitude and significance.

In the unrestricted version of the Solow model (upper panel of Table 2.1, columns 2 and 3), the coefficient estimate on $\ln s_{ik}$ decreases from 1.4240 to 1.0024 remaining very significant and the coefficient estimate on $\ln(n_i + g + \delta)$ increases from -1.9898 to -1.0991 but becomes highly insignificant. In the unrestricted *basic Solow-CES model*, the quadratic term $\left[\ln\left(\frac{s_{ik}}{n_i+g+\delta}\right)\right]^2$ has a significant point estimate of 0.3345 providing evidence in favor of a two-factor CES specification over the commonly used CD specification.

Estimates from the restricted model (lower panel of Table 2.1, columns 2 and 3) show that employing the CES specification lowers the value of α from 0.5981, to 0.4984. We also find that the implied elasticity of substitution is greater than unity ($\sigma = 1.5425$) but is statistically significant only at the 13% level.

Recall, that whereas in the CD specification α is the share of capital in output, in the CES specification it is a distribution parameter. The physical capital share of country i in the two-factor CES production function is given by $shr(K_i) =$

Table 2.1: Cross-Country regressions with CD and CES technologies (PWT 4.0)

Specification	Basic Solow (PWT 4.0) CD (Eq.2.1)	Basic Solow (PWT 4.0) CES (Eq.2.4)	Extended Solow (PWT 4.0) CD (Eq.2.2)	Extended Solow (PWT 4.0) CES (Eq.2.6)
Unrestricted				
Constant	8.0353*** (1.2377)	7.1333*** (1.5056)	8.6592*** (0.8071)	6.3207*** (0.8965)
$\ln s_{ik}$	1.4240*** (0.1299)	1.0024*** (0.2088)	0.6967*** (0.1454)	1.1712** (0.5164)
$\ln(n_i + g + \delta)$	−1.9898*** (0.5368)	−1.0991 (0.8290)	−1.7452*** (0.3369)	−1.0581** (0.4887)
$\ln s_h$	—	—	0.6545*** (0.0726)	0.4814 (0.3054)
$[\ln s_{ik} - \ln(n_i + g + \delta)]^2$	—	0.3345* (0.1774)	—	0.1113 (0.1606)
$[\ln s_{ih} - \ln(n_i + g + \delta)]^2$	—	—	—	0.2586*** (0.0736)
$[\ln s_{ik} - \ln s_{ih}]^2$	—	—	—	−0.2116*** (0.0973)
s.e.e.	0.69	0.68	0.51	0.47
Adj. R^2	0.59	0.60	0.78	0.81
Obs.	98	98	98	98
Restricted				
Constant	6.8724*** (0.1027)	6.9370*** (0.0890)	7.8531*** (0.1572)	7.8749*** (0.1376)
Implied α	0.5981*** (0.0170)	0.4984*** (0.0499)	0.3082*** (0.0465)	0.2395*** (0.0406)
Implied β	—	—	0.2743*** (0.0356)	0.3582*** (0.0431)
Implied σ	1	1.5425 (0.5574)	1	1.1894††† (0.0449)
s.e.e.	0.69	0.68	0.51	—
Adj. R^2	0.59	0.60	0.78	—
Obs.	98	98	98	98

Notes: It is assumed that $g + \delta = 0.05$ as in MRW. α and β are shares of physical and human capital respectively in the CD models (distribution parameters in the CES models). All regressions are estimated using OLS with the exception of the restricted version of the *extended Solow-CES model* which was estimated using NLLS. Standard errors are given in parentheses. The standard errors for α and β were recovered using standard approximation methods for testing nonlinear functions of parameters. White's heteroskedasticity correction was used. *** (†††) Significantly different from 0 (1) at the 1% level. ** (††) Significantly different from 0 (1) at the 5% level. * (†) Significantly different from 0 (1) at the 10% level.

$\frac{\alpha k_i^{\frac{\sigma-1}{\sigma}}}{\alpha k_i^{\frac{\sigma-1}{\sigma}}+(1-\alpha)}$, where $\frac{\partial shr(K_i)}{\partial k_i} > 0$ and $\frac{\partial shr(K_i)}{\partial \sigma} > 0$. It is possible to calculate steady-state capital shares ($shr(K_i^*)$) by using our estimated coefficients for $\alpha = 0.4984$ and $\sigma = 1.5425$, and by obtaining each country's steady-state capital per augmented labor implied by the *basic Solow-CES model*

$$k_i^* = \left[\frac{(1-\alpha)}{\left(\frac{n_i+g+\delta}{s_{ik}}\right)^{\frac{\sigma-1}{\sigma}} - \alpha}\right]^{\frac{\sigma}{\sigma-1}}, \qquad (2.7)$$

where n_i is population growth rate and s_{ik} is savings rate in country i. We show that the implied capital shares increase with the level of physical capital per augmented labor and that they vary considerably across countries.[9]

2.3.2 Extended Solow Regression Results

Columns 4 and 5 of Table 2.1 report results from the *extended Solow-CD* and *extended Solow-CES* regressions, respectively. All of the regressions are estimated by ordinary least squares (OLS) with the exception of the restricted version of the highly nonlinear *extended Solow-CES equation* (2.6) which was estimated by nonlinear least squares (NLLS).

In terms of overall fit, we find that the unrestricted and restricted Solow-CES models are slight improvements over the corresponding Solow-CD models. Coefficient estimates obtained from both the restricted and unrestricted versions of the *extended Solow-CES specification* are considerably different from those obtained under the *extended Solow-CD specification.*

In the unrestricted model (upper panel of Table 2.1, columns 4 and 5), the estimated coefficient for physical capital increases substantially in magnitude from 0.6967 to 1.1712 but decreases in significance level from 1% to 5%, whereas the coefficient on human capital decreases from 0.6545 to 0.4814 and becomes insignificant.

[9]Derivation of equation (2.7) is shown in Appendix B. Physical (and human) capital shares for all 98 countries obtained from the *basic* (and *extended*) *Solow-CES models* are reported in Table A3 in Appendix A.

Notice that two out of the three quadratic terms due to the CES specification are significant. In particular, the estimated coefficient for the quadratic human capital term $\left[\ln\left(\frac{s_{ih}}{n_i+g+\delta}\right)\right]^2$ is highly significant as is the coefficient for the quadratic term $\left[\ln\left(\frac{s_{ik}}{s_{ih}}\right)\right]^2$, whereas the quadratic physical capital term $\left[\ln\left(\frac{s_{ik}}{n_i+g+\delta}\right)\right]^2$ is insignificant. In the restricted model, the physical capital distribution parameter α equals 0.2395 whereas the human capital distribution parameter β equals 0.3582 and both are significant at the 1% level. Most importantly, the elasticity of substitution parameter, σ, equals 1.1894 and it is statistically different from unity at the 1% level.[10]

Once again, recall that under CES technology, α and β are not shares but distributions parameters. Physical capital share is now given by $shr(K_i) = \frac{\alpha k_i^{\frac{\sigma-1}{\sigma}}}{\alpha k_i^{\frac{\sigma-1}{\sigma}}+\beta h_i^{\frac{\sigma-1}{\sigma}}+(1-\alpha-\beta)}$ and human capital share by $shr(H_i) = \frac{\beta h_i^{\frac{\sigma-1}{\sigma}}}{\alpha k_i^{\frac{\sigma-1}{\sigma}}+\beta h_i^{\frac{\sigma-1}{\sigma}}+(1-\alpha-\beta)}$. We calculate steady-state physical and human capital shares ($shr(K_i^*)$, $shr(H_i^*)$) by using our estimated coefficients for $\alpha = 0.2395$, $\beta = 0.3582$ and $\sigma = 1.1894$, and by obtaining each country's steady-state physical and human capital per augmented labor values implied by the *extended Solow-CES model*[11]

$$k_i^* = \left[\frac{1-\alpha-\beta}{\left(\frac{n_i+g+\delta}{s_{ik}}\right)^{\frac{\sigma-1}{\sigma}} - \beta\left(\frac{s_{ih}}{s_{ik}}\right)^{\frac{\sigma-1}{\sigma}} - \alpha}\right]^{\frac{\sigma}{\sigma-1}} \tag{2.8}$$

[10]We have also estimated the restricted version of the *extended Solow-CES equation* (2.6) by employing a two-stage conditional estimation procedure. First, we estimated equation (2.6) using OLS and then recovered the implied values of the distribution parameters for physical capital (α) and human capital (β). We then re-estimated equation (2.6) conditional on the implied values of α and β in order to recover the implied elasticity of substitution parameter σ. The coefficient estimates from the two-stage conditional estimation are as follows:

Constant	Implied α	Implied β	Implied σ	Adj. R^2
7.5359***	0.4452***	0.1751	1.1923†††	0.81
(0.3252)	(0.1582)	(0.1277)	(0.0611)	

The notation in Table 2.1 applies to the above panel. These estimates are consistent with the NLLS estimation. In particular, the implied value of σ is slightly higher than in the NLLS estimation and significantly different from unity. Although the estimators from the two-stage conditional estimation are consistent, they are not efficient because equation (2.6) is over-identified.

[11]Derivation of equations (2.8-2.9) is shown in Appendix B.

$$h_i^* = \left[\frac{1-\alpha-\beta}{\left(\frac{n_i+g+\delta}{s_{ih}}\right)^{\frac{\sigma-1}{\sigma}} - \alpha\left(\frac{s_{ik}}{s_{ih}}\right)^{\frac{\sigma-1}{\sigma}} - \beta} \right]^{\frac{\sigma}{\sigma-1}}. \tag{2.9}$$

This exercise reveals that there still exists considerable heterogeneity among the estimated physical and human capital shares across countries, but it is lower than that found in the *basic Solow-CES model*. In particular, we find that the implied physical capital shares range from 0.2283 in Ethiopia to 0.3169 in Japan, whereas implied human capital shares range from 0.2232 in Rwanda to 0.4006 in Finland.[12,13]

2.3.3 Robustness Analysis of the Results

In this section we examine the robustness of our results to the updated PWT 6.0 dataset which has recently been used in Bernanke and Gürkaynak (2001). This preliminary version of PWT extends the coverage of the data for another decade from $1960-1995$ for 90 out of the 98 countries in the original sample.

The results from this exercise are presented in Table 2.2. Columns 2 and 4 replicate the results in Bernanke and Gürkaynak for the *basic* and *extended Solow-CD models*. Qualitatively, these results are similar to those of MRW in Table 2.1. A noticeable difference is that using the 1960-1995 sample period increases the fit of the models (Adj. R^2 increases approximately 10% in each model). Column 3 presents results for the *basic Solow-CES model*. In general, there is stronger evidence in favor of the CES specification. For instance, in the unrestricted version of the model (upper panel of Table 2.2), the main difference from the baseline results is that although the quadratic term $\left[\ln\left(\frac{s_{ik}}{n_i+g+\delta}\right)\right]^2$ decreases in magnitude from 0.3345 to 0.1786, it increases in significance from the 10% to the 5% level. More importantly,

[12]Physical (and human) capital shares for all 98 countries obtained from the *basic* (and *extended*) *Solow-CES models* are reported in Table A3 in Appendix A.

[13]One of Kaldor's (1961) "stylized facts" of economic growth, is that the shares of income accruing to capital and labor are relatively constant over time. This view has been first challenged by the pioneer paper of Solow (1958) and remains today an open research question (i.e. see Gollin (2002) who finds that labor's share of national income across 31 countries is relatively constant). As shown in Table A3, our results suggest that physical and human capital shares vary considerably across countries and increase with economic development.

Table 2.2: Cross-Country regressions with CD and CES technologies (PWT 6.0)

Specification	Basic Solow (PWT 6.0) CD (Eq.2.1)	Basic Solow (PWT 6.0) CES (Eq.2.4)	Extended Solow (PWT 6.0) CD (Eq.2.2)	Extended Solow (PWT 6.0) CES (Eq.2.6)
Unrestricted				
Constant	11.4624*** (1.0444)	10.3608*** (1.2808)	11.1775*** (0.6869)	8.5420*** (0.8256)
$\ln s_{ik}$	1.0729*** (0.1112)	0.9870*** (0.0926)	0.5372*** (0.1307)	0.8826*** (0.1422)
$\ln(n_i + g + \delta)$	−2.6594*** (0.4443)	−2.0670*** (0.8290)	−2.3495*** (0.2741)	−1.3754*** (0.3352)
$\ln s_h$	—	—	0.6472*** (0.0959)	0.5138*** (0.1692)
$[\ln s_{ik} - \ln(n_i + g + \delta)]^2$	—	0.1786** (0.0880)	—	0.1414** (0.0615)
$[\ln s_{ih} - \ln(n_i + g + \delta)]^2$	—	—	—	0.2033*** (0.0725)
$[\ln s_{ik} - \ln s_{ih}]^2$	—	—	—	−0.2043*** (0.4476)
s.e.e.	0.61	0.60	0.48	0.46
Adj. R^2	0.68	0.69	0.80	0.82
Obs.	90	90	90	90
Restricted				
Constant	8.2439*** (0.0883)	8.1295*** (0.0832)	8.8431*** (0.1214)	8.5852*** (0.1071)
Implied α	0.5494*** (0.0194)	0.5035*** (0.0198)	0.2681*** (0.0526)	0.3679*** (0.0545)
Implied β	—	—	0.2963*** (0.0480)	0.2142*** (0.0633)
Implied σ	1	1.3706†† (0.1534)	1	1.1337††† (0.0404)
s.e.e.	0.63	0.61	0.50	—
Adj. R^2	0.66	0.68	0.79	—
Obs.	90	90	90	90

Notes: It is assumed that $g + \delta = 0.05$ as in MRW. α and β are shares of physical and human capital respectively in the CD models (distribution parameters in the CES models). All regressions are estimated using OLS with the exception of the restricted version of the *extended Solow-CES model* which was estimated using NLLS. Standard errors are given in parentheses. The standard errors for α and β were recovered using standard approximation methods for testing nonlinear functions of parameters. White's heteroskedasticity correction was used. *** (†††) Significantly different from 0 (1) at the 1% level. ** (††) Significantly different from 0 (1) at the 5% level. * (†) Significantly different from 0 (1) at the 10% level.

in the restricted version (lower panel of Table 2.2) the implied elasticity of substitution parameter σ is equal to 1.3706 and is now significantly different from unity at the 5% level. This is a substantial improvement of the coefficient estimate of σ over the 13% significance level of the same coefficient in Table 2.1.

Column 5 presents coefficient estimates of the *extended Solow-CES model*. Results are qualitatively similar to those in Table 2.1. In the unrestricted version (upper panel of Table 2.2) notice that now all coefficient estimates are significant (even the quadratic term $\left[\ln\left(\frac{s_{ik}}{n_i+g+\delta}\right)\right]^2$ which was insignificant in Table 2.1). In the restricted model the implied value of σ decreases slightly from 1.1894 to 1.1337 but remains highly significant. Consistent with our baseline results regarding input shares, is our finding that physical and human capital shares in the *basic* and *extended Solow-CES models* vary considerably.[14]

Legitimate concerns can be raised on the validity of statistical inference based on test statistics with asymptotic properties when using small samples. In order to check whether specific parameter estimates or the general results are not unduly influenced by assumptions on error distribution, we also checked the sensitivity of these results by using bootstrapping. Specifically, we checked whether the linear estimation results in Tables 2.1 and 2.2 are unusual relative to $10,000$ parameter estimates obtained from randomly sampled residuals from the original model. We find that although there are slight differences in magnitudes of estimates and corresponding standard errors at two decimal places (hundredth point), our qualitative implications are robust.

Our cross-sectional analysis is subject to two additional econometric problems. First, the problem of endogeneity maybe present because variables used as regressors (i.e. physical and human capital investment) maybe influenced by the

[14]Physical and human capital shares for all 90 countries in the updated PWT 6.0 dataset obtained from the *basic* and *extended Solow-CES models* are reported in Table A3 in Appendix A.

same factors that influence output. Second, the choice of variables in the regression model is not clear therefore giving rise to the "model uncertainty" problem.

The most common practice to resolving the endogeneity problem has been the use of instrumental variable approaches. However, in cross-country regressions treatment of endogeneity problems is less than satisfactory because of lack of viable exogenous instruments. Brock and Durlauf (2000) and Durlauf (2001), among others, observe that studies using instrumental variables (IV) to address endogeneity are not convincing as their choice of instruments do not meet the necessary exogeneity requirements.[15] In addition, Romer (2001) shows that IV estimation potentially introduces an upward bias in the parameter estimates due to the fact that most measures of physical and human capital used in the literature vary with levels of per capita output.

Recent concerns about the appropriate choice of explanatory variables are also valid. The vast number of potential explanatory variables that could be included in any level or growth regression creates the need for procedures that assign some level of confidence to each of these variables.[16] A first attempt to test the importance of explanatory variables is made by Sala-i-Martin (1997). A recent and very promising line of research for identifying effective regressors is based on Bayesian Model Averaging (see Fernàndez, Ley and Steel (2001)).

Even though we are in complete agreement with these concerns, we have also tried to resolve potential mispecification error from choice of explanatory variables, by incorporating variables whose explanatory power was established to be robust by Sala-i-Martin (1997) and Fernàndez, et al. (2001). In particular, we added to our regressors a measure of longevity (life expectancy), a measure of openness (number of years the economy has been open), a measure of political stability (number of coups) and a measure for geographical externality (latitude). Longevity, openness

[15]For more on this issue see Brock and Durlauf (2000, pp.9-11) and Durlauf (2001, p.66).

[16]For an extensive discussion on "model uncertainty" see Brock and Durlauf (2000, pp.6-8) and Durlauf (2001, p.67).

and latitude have positive effect on per capita output while, as expected, coups have a negative impact on per capita output. The qualitative implications of our model are generally robust to inclusion of these variables, however, due to the small sample size (our sample was reduced to 70 countries) it is difficult to capture the quadratic curvature of the production function leading to smaller elasticity of substitution and negative share for human capital.

In summary, our key finding in this section is that in the context of cross-country level regressions we can reject the CD aggregate production specification over the more general CES specification. In particular, we find evidence that the elasticity of substitution parameter σ is greater than unity in both the basic and the extended models. The primary implication of our results for the empirical literature is that the vast majority of cross-country level regressions may be mispecified due to the choice of aggregate production specification. The additional quadratic term(s) appearing in the basic (extended) Solow-CES specification reflect the omitted term(s) responsible for the specification error.

2.4 Thresholds and Regimes in Solow-CES Models

In our analysis so far we have shown that the CD aggregate production technology (a necessary condition for the linearity of the Solow growth model), assumed in the vast majority of existing studies, is rejected over the more general CES aggregate technology. In this section we investigate whether nonlinearities in the CES production function can explain the *parameter heterogeneity* evident in growth regressions. Put differently, we investigate the possibility that replacing the (identical for all countries and linear) CD specification with the (identical for all countries but nonlinear) CES specification can potentially capture the differences among complex heterogenous objects such as countries.

2.4.1 Threshold Estimation

We follow Hansen (2000) to search for multiple regimes in the data under the Solow model with CES production technology. Hansen develops a statistical theory of threshold estimation in the regression context that allows for cross-section observations. Least squares estimation is considered and an asymptotic distribution theory for the regression estimates is developed. The main advantage of Hansen's methodology over, for instance, the Durlauf-Johnson regression-tree model is that the former is based on an asymptotic distribution theory which can formally test the statistical significance of regimes selected by the data.[17]

In much of the empirical growth literature, the cross-country growth regression equation based on the CD specification takes the form

$$\gamma_i = \ln A(0) - \theta \ln \left(\frac{Y}{L}\right)_{i,60} + \theta \frac{\alpha}{1-\alpha-\beta} \ln \left(\frac{s_{ik}}{n_i+g+\delta}\right) + \theta \frac{\beta}{1-\alpha-\beta} \ln \left(\frac{s_{ih}}{n_i+g+\delta}\right), \quad (2.10)$$

where $\gamma_i = \ln\left(\frac{Y}{L}\right)_{i,85} - \ln\left(\frac{Y}{L}\right)_{i,60}$ is the average growth rate of output between 1960 and 1985, $\theta = (1 - e^{-\lambda t})$, λ is the convergence rate, and $(Y/L)_{i,60}$ is the initial per capita output in country i. Under CES technology this cross-country growth regression equation now becomes

$$\begin{aligned}\gamma_i = {} & \ln A(0) - \theta \ln \left(\frac{Y}{L}\right)_{i,60} + \theta \frac{\alpha}{1-\alpha-\beta} \ln \left(\frac{s_{ik}}{n_i+g+\delta}\right) + \theta \frac{\beta}{1-\alpha-\beta} \ln \left(\frac{s_{ih}}{n_i+g+\delta}\right) + \\ & \frac{1}{2}\theta \frac{\sigma-1}{\sigma} \frac{1}{(1-\alpha-\beta)^2} \left\{ \alpha \left[\ln\left(\frac{s_{ik}}{n_i+g+\delta}\right)\right]^2 + \beta \left[\ln\left(\frac{s_{ih}}{n_i+g+\delta}\right)\right]^2 - \alpha\beta \left(\ln \frac{s_{ik}}{s_{ih}}\right)^2 \right\}. \quad (2.11)\end{aligned}$$

Following Durlauf and Johnson (1995) and Hansen (2000), we search for multiple regimes in the data using initial per capita output ($(Y/L)_{60}$) and initial adult literacy rates (LIT_{60}) as potential threshold variables.[18] Since Hansen's statistical theory allows for one threshold for each threshold variable, we proceed by selecting

[17] For a detailed discussion of the statistical theory for threshold estimation in linear regressions, see Hansen (2000).

[18] In order to compare our model predictions to those of Durlauf and Johnson (1995) and Hansen (2000) we only consider the two threshold variables considered in these papers. In chapter 4 we extend these results to other potential threshold variables.

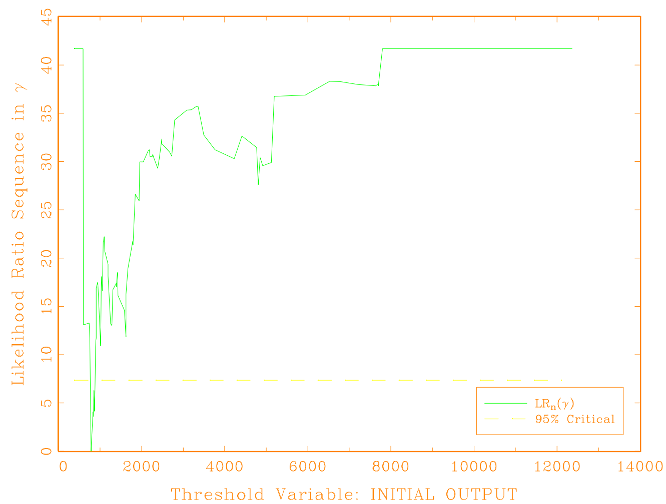

Figure 2.1: First sample split

between the two variables by employing the heteroskedasticity-consistent Lagrange Multiplier test for a threshold obtained in Hansen (1996). With the exception of adult literacy rates (LIT_{60}), the variables employed in this exercise are identical to those used in the regression analysis of the previous section (PWT 4.0). Adult literacy rates is defined as the fraction of population over the age of 15 that is able to read and write in 1960; data are from the World Bank's *World Report*. The sample used in this exercise includes 96 of the 98 countries in the original sample after eliminating Botswana and Mauritius for which there are no data on initial literacy rates.

In the first round of splitting, we find that the threshold model using initial output is significant with p-value at 0.025 while the threshold model using initial literacy rates is significant with p-value at 0.002. These results indicate that there maybe a sample split based on either output or literacy rate. We choose to first examine the sample split for the threshold model using output, deferring discussion on the threshold model using literacy rates for later on.

Figure 2.1 presents the normalized likelihood ratio sequence $LR_n^*(\gamma)$ statistic as a function of the output threshold. The least-squares estimate γ is the value that

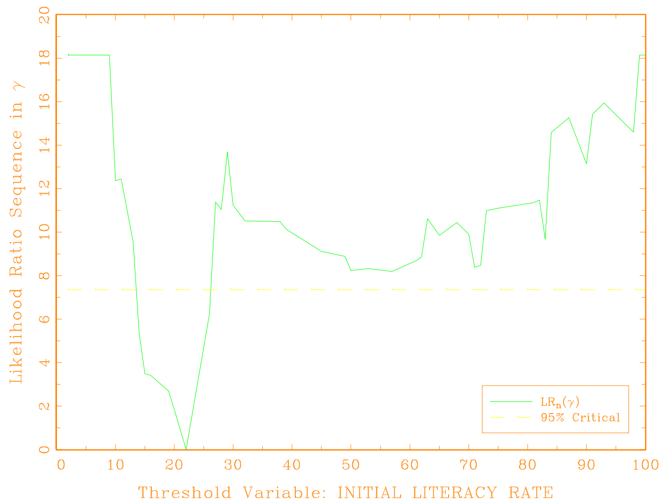

Figure 2.2: Second sample split

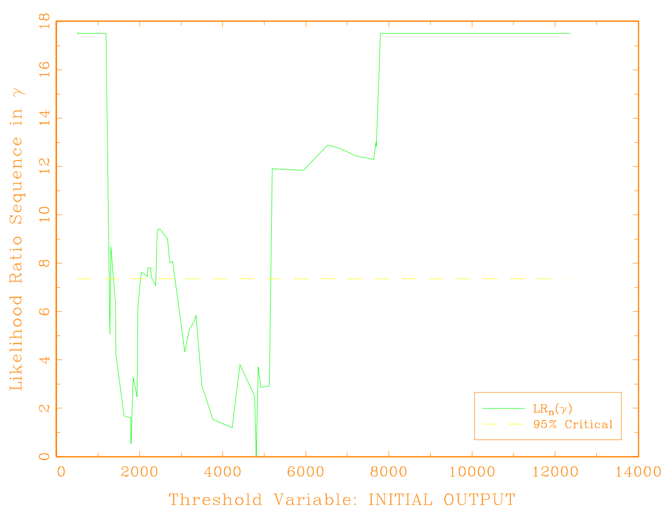

Figure 2.3: Third sample split

minimizes the function $LR_n^*(\gamma)$ which occurs at $\hat{\gamma} = \$777$. The asymptotic 95% critical value (7.35) is shown by the dotted line and where it crosses $LR_n^*(\gamma)$ displays the confidence set $[\$777, \$863]$. The first output threshold divides our sub-sample of 96 countries into a low-income group with 14 countries and a high-income group with 82 countries.

Even though further splitting of the low-income group is not possible, further splitting of the high-income group is shown to be possible. The threshold model using literacy rates is significant attaining a p-value of 0.075. Figure 2.2 presents the normalized likelihood ratio statistic as a function of the literacy rates threshold. The point estimate for the literacy threshold is $\hat{\gamma} = 22\%$ with the 95% confidence interval $[14\%, 26\%]$. The literacy rates threshold variable splits the high-income sub-sample of 82 countries into two additional groups; the low-literacy group with 21 countries and the high-literacy group with 61 countries.

Our third and final round of threshold model selection involves the 61 countries with initial per capita output above \$777 and initial literacy rates above 22%. We find that the threshold model using output is significant with p-value at 0.056. The output threshold value occurs at \$4802 and the asymptotic 95% confidence set is $[\$1430, \$5119]$. The normalized likelihood ratio statistic as a function of the output threshold is illustrated in Figure 2.3. The output threshold variable splits the high-literacy group into a high-literacy-low-income group with 40 countries and a high-literacy-high-income group with 21 countries. We have tried to further split these subsamples, but none of the bootstrap test statistics were significant and therefore no further splitting was possible using the existing threshold variables.

Figure 2.4 uses tree diagrams to compare our threshold estimation results obtained under the *extended Solow-CES model* with Hansen (2000) results obtained under the *extended Solow-CD model*. Non-terminal and terminal nodes are represented by squares and circles, respectively. The numbers inside the squares and circles show the number of countries in each node. The point estimates for each threshold

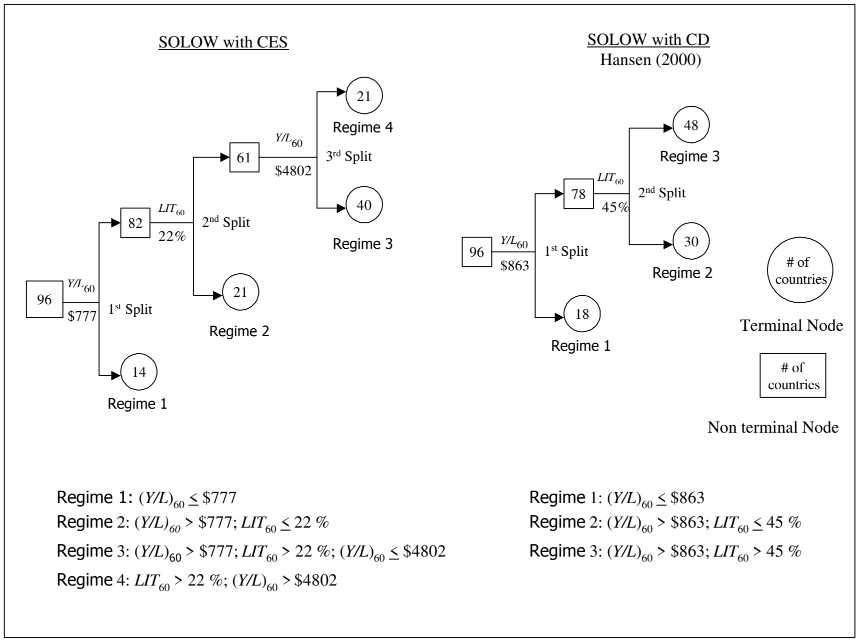

Figure 2.4: Thresholds in the Solow-CES model vs the Solow-CD model

variable are presented on the rays connecting the nodes. It is clear from Figure 2.4 that replacing the CD with the CES specification in the Solow model increases the number of endogenously determined regimes from three to four. Moreover, the composition of these regimes is different across models. Table 2.3 presents the countries in each regime obtained from our threshold estimation of the Solow model with CES aggregate production technology.

2.4.2 Regression Results

Next, we turn our attention to the estimation of equation (2.11) for the four regimes. Table 2.4 presents estimates for each regime in the unrestricted and restricted models. These estimates provide strong evidence in favor of parameter heterogeneity and the presence of multiple regimes. The heterogeneity of the coefficient estimates across regimes is evident, as coefficient estimates vary considerably in sign and magnitude.

Table 2.3: Country classification in the Solow-CES model

Regime 1	Regime 2	Regime 3		Regime 4
B. Faso	Algeria	Bolivia	Madagascar	Argentina
Burma	Angola	Brazil	Malaysia	Australia
Burundi	Bangladesh	Colombia	Mexico	Austria
Ethiopia	Benin	Costa Rica	Nicaragua	Belgium
Malawi	C. Afri. Rep.	Dom. Rep.	Panama	Canada
Mali	Cameroon	Ecuador	Papua N. G.	Chile
Mauritania	Chad	Egypt	Paraguay	Denmark
Niger	Congo	El Salvador	Peru	Finland
Rwanda	Haiti	Ghana	Philippines	France
Sierra Leone	I. Coast	Greece	Portugal	Italy
Tanzania	Kenya	Guatemala	S. Africa	N. Zealand
Togo	Liberia	Honduras	S. Korea	Netherlands
Uganda	Morocco	Hong Kong	Singapore	Norway
Zaire	Mozambique	India	Spain	Sweden
	Nepal	Indonesia	Sri Lanka	Switzerland
	Nigeria	Ireland	Syria	Tri. & Tobago
	Pakistan	Israel	Thailand	U.K.
	Senegal	Jamaica	Turkey	U.S.A.
	Somalia	Japan	Zambia	Uruguay
	Sudan	Jordan	Zimbabwe	Venezuela
	Tunisia			W. Germany
(14)	(21)	(40)		(21)

Starting with the unrestricted model (upper panel of Table 2.4), in all but Regime 4 the sign of the coefficient on initial income, $\ln(Y/L)_{i,60}$, has the expected negative sign which is consistent with conditional convergence. Point estimates on $\ln(Y/L)_{i,60}$ vary from -1.2413 and significant at the 1% level in Regime 1, to 0.2750 and significant at the 10% level in Regime 4. There is considerable variation in the estimates associated with physical capital as well. The coefficient estimates on physical capital investment, $\ln s_{ik}$, vary from 1.3082 in Regime 1 to 2.4887 in Regime 3, and in all regimes the coefficients are significant at the 1% level. In contrast, estimated coefficients on human capital investment, $\ln s_{ih}$, provide mixed results. In three of the four regimes, the coefficients have negative sign. Estimated coefficients vary from -1.4007 in Regime 4 to 0.6860 in Regime 2. Parameter heterogeneity across regimes is equally evident in the quadratic terms $[\ln s_{ih} - \ln(n_i + g + \delta)]^2$ and $[\ln s_{ik} - \ln s_{ih}]^2$. In two of the four regimes (Regimes 1 and 2) the coefficient associated with $[\ln s_{ih} - \ln(n_i + g + \delta)]^2$ is significant and varies in magnitude from 0.1565 in Regime 1 to 0.6551 in Regime 2. In all regimes the coefficient for $[\ln s_{ik} - \ln s_{ih}]^2$ is significant and ranges from -0.6986 in Regime 4 to 0.1262 in Regime 1. Coefficient estimates for $[\ln s_{ih} - \ln(n_i + g + \delta)]^2$ are insignificant in Regime 2-4 and positive and significant in Regime 1.

Disparity in coefficient estimates across regimes in the restricted model (lower panel of Table 2.4) is as large as in the unrestricted model. Recall that, the coefficients of the restricted model are estimated using NLLS. The estimated distribution parameter for physical capital (α) is significant in three out of the four regimes (1, 3 and 4) and varies from 0.0514 in Regime 2 to 0.6770 in Regime 3. Similarly, the estimated distribution parameter for human capital (β) is substantially different across regimes ranging from 0.1768 in Regime 1 to 0.8089 in Regime 2.[19] It is worth noting that unlike the vast majority of growth regressions, under the restricted model, the distribution parameters of physical *and* human capital take economically feasible values. Finally, the coefficient estimates of the elasticity of substitution parameter (σ) vary from 0.9861 in Regime 4 to 1.9524 in Regime 1.[20,21] Of course, one should interpret these results with caution as σ (reflecting the curvature of the production function) maybe difficult to capture by our estimation given the limited number of observations in each regime.[22]

[19] This result is consistent with Kalaitzidakis et al. (2001) and Kourtellos (2001) who find strong nonlinear effects of human capital on economic growth.

[20] This result is qualitatively consistent with Duffy and Papageorgiou (2000) and Miyagiwa and Papageorgiou (forthcoming) who argue that the elasticity of substitution may vary along the development path.

[21] Physical and human capital shares for all 96 countries were calculated using regression estimates from the four regimes. As expected, these shares vary considerably more than shares estimated using an identical CES production function (presented in Table A3). These results are available by the authors upon request.

[22] Given the small number of observations in each regime, we have tried implementing the bootstrap which performs inference that is more reliable in finite samples than inferences based on conventional asymptotic theory. Unfortunately, in our work bootstrap replication involves nonlinear estimation that fails to converge.

Table 2.4: Cross-country growth regressions for the four regimes

Specification	Regime 1	Regime 2	Regime 3	Regime 4
Unrestricted				
Constant	7.9977^{***}	3.1754^{***}	-1.9041	-0.9464
	(1.4756)	(0.6411)	(1.3274)	(1.1087)
$\ln(Y/L)_{i,60}$	-1.2413^{***}	-0.6636^{***}	-0.0899	0.2749^{*}
	(0.1695)	(0.1138)	(0.1041)	(0.1327)
$\ln s_{ik}$	1.3082^{***}	1.8882^{***}	2.4887^{***}	1.9214^{***}
	(0.2074)	(0.4339)	(0.5310)	(0.6145)
$\ln s_{ih}$	-0.5339^{*}	0.6860^{*}	-1.1949^{***}	-1.4007^{*}
	(0.2362)	(0.3496)	(0.3171)	(0.7358)
$\ln(n_i + g + \delta)$	-1.0533^{*}	-1.3673^{***}	-0.4437	-1.7911^{***}
	(0.4567)	(0.2834)	(0.7727)	(0.1832)
$[\ln s_{ik} - \ln(n_i + g + \delta)]^2$	0.3469^{**}	-0.0573	-0.1993	-0.0089
	(0.1350)	(0.1298)	(0.2175)	(0.1036)
$[\ln s_{ih} - \ln(n_i + g + \delta)]^2$	0.1565^{*}	0.6551^{***}	0.1889	-0.0189
	(0.0719)	(0.0900)	(0.2018)	(0.3246)
$[\ln s_{ik} - \ln s_{ih}]^2$	-0.2595^{***}	0.1262^{***}	-0.5770^{***}	-0.6986^{**}
	(0.0518)	(0.0299)	(0.1268)	(0.2546)
s.e.e.	0.14	0.10	0.32	0.13
Adj. R^2	0.78	0.81	0.51	0.85
Obs.	14	21	40	21
Restricted				
Constant	5.5065^{***}	3.4453^{***}	-0.4663	-0.0784
	(1.3538)	(1.0862)	(1.0103)	(1.2500)
Implied α	0.2144^{***}	0.0289	0.3779^{**}	0.3302^{***}
	(0.0419)	(0.0450)	(0.1153)	(0.0808)
Implied β	0.1289	0.5889^{***}	0.1154^{*}	0.2437^{***}
	(0.1551)	(0.0623)	(0.0632)	(0.0590)
Implied σ	2.1405	$1.1604^{\dagger\dagger\dagger}$	0.8487	0.9054
	(1.1196)	(0.0155)	(0.1316)	(0.2424)
Obs.	14	21	40	21

Notes: α and β are distribution parameters of physical and human capital respectively. Standard errors are given in parentheses. The standard errors for α and β were recovered using standard approximation methods for testing nonlinear functions of parameters. White's heteroskedasticity correction was used. *** (†††) Significantly different from 0 (1) at the 1% level. ** (††) Significantly different from 0 (1) at the 5% level. * (†) Significantly different from 0 (1) at the 10% level.

2.4.3 Alternative Sample Splitting

Next, we examine the alternative model in which the first-round threshold variable is initial adult literacy rates (recall that the bootstrap procedure obtained a p-value of 0.002). The literacy rates threshold value occurs at 25% and the asymptotic 95% confidence set is $[15\%, 26\%]$. This threshold value divides our original sample of 96 countries into a low-literacy group with 32 countries and a high-literacy group with 64 countries. We show that further splitting is possible in both of these subsamples. The low-literacy group is split using initial output obtaining a p-value equal to 0.052. The threshold value is $863 and the confidence set is $[\$846, \$863]$. The low-literacy sub-sample (32 countries) is split into a low-literacy-low-income group with 15 countries and a low-literacy-high-income group with 17 countries. The high-literacy group (64 countries) can also be split by using initial output as the threshold variable, with p-value equal to 0.003. The point estimate for the initial output threshold is $4802 and the confidence interval is $[\$1285, \$5119]$. The high-literacy sub-sample is divided into a high-literacy-low-income group with 43 countries and a high-literacy-high-income group with 21 countries. Figure A1 in Appendix A illustrates the likelihood ratio statistic as a function of the relevant threshold variables. Figure A2 presents a regression tree of this alternative splitting scheme and Table A1 presents the countries under each of the four regimes.

One of the findings that is immediately noticeable is that employing literacy rates as the first-round threshold variable obtains similar regimes (terminal nodes) to those obtained when using output as the first-round threshold variable. In fact Regime 4 is identical in both cases while Regimes 1-3 are quite similar. When using literacy for the initial splitting, Regime 1 attains 15 countries (1 country more than in the case where output is used for the initial splitting), Regime 2 attains 17 countries (4 countries less than Regime 2 in the first case), and Regime 3 attains 43 countries (3 countries more than the first case). In terms of the composition of regimes across the two alternative cases, most notable is the difference in Regime 1 (compare Tables 2.3 and A1). As shown in Table A2, regression estimates for each of the four regimes under this alternative model vary substantially which is consistent with the original model. The lower panel of Table A2 shows that the distribution parameters of physical *and* human capital take economically feasible values and all but two estimates are significant at the 1% level.

To summarize, the key finding of this exercise is twofold: First, the Solow model with CES technology provides strong evidence in favor of parameter heterogeneity and the presence of multiple regimes. Second, whereas under the CD aggregate technology the statistical theory of threshold estimation identifies three regimes, under the CES technology it identifies four regimes. In addition to the number of regimes identified, the composition of each regime has also changed under the CES model. We conclude this section with a puzzling observation. The number and composition of the regimes identified here is surprisingly similar to those in Durlauf and Johnson (1995). We do not have an explanation to offer but we suspect that this, like many other puzzles, maybe an optical illusion.

2.5 Conclusion

In this paper we set out to examine whether nonlinearities in the production function can explain parameter heterogeneity in growth regressions. Our investigation involves two sequential steps. First, we question the empirical relevance of the CD aggregate production specification in cross-country linear regressions. We find that both in the basic and the extended regression models the CD specification is rejected over the more general CES specification with elasticity of substitution greater than unity. We also find that the CES specification better fits cross-country variation than the CD specification. Our findings call into question a number of earlier cross-country level regression exercises that simply assume a CD specification for the aggregate input-output relationship. In particular, we argue that the vast majority of cross-country regressions may be mispecified due to the choice of aggregate production specification. A simple test of aggregate production specification is to add the quadratic term(s) appearing in the basic (extended) Solow-CES specification and examine the significance of the estimated coefficients.

Given our first result, we then search for multiple regimes in the data by replacing the CD with the CES specification. By using the endogenous threshold methodology of Hansen (2000), we show that the Solow model under CES continues to imply robust nonlinearities in the growth process that are consistent with the presence of multiple regimes. This finding re-enforces the findings of Durlauf and Johnson (1995), Durlauf, Kourtellos and Minkin (2001) and Kourtellos (2001), and is in stark contrast with the prevalent practice in growth literature in which countries are assumed to obey a common linear international production function. Furthermore, this result suggests that an identical to all countries CES aggregate production function can not capture the heterogeneity that exists across countries therefore shifting attention to growth nonlinearities and omitted growth determinants as two alternative interpretations of parameter heterogeneity.

Our findings can be further enriched by extending this analysis on at least two fronts. First, use the CES specification in alternative econometric techniques relevant to parameter heterogeneity as the semiparametric varying coefficient model along the lines of Hastie and Tibshirani (1992) and Kourtellos (2001). Second, it is worth examining the quantitative and qualitative implications of our findings when different threshold variables are used. Such variables may include life expectancy, ethnicity and openness, just to name a few.

Chapter 3

Determinants of Economic Growth in Africa

3.1 Introduction

Although generating sustained economic growth in Sub-Saharan Africa remains the most pressing challenge to global development (Block, 2001), little is known about the determinants of economic growth in Africa. Owing primarily to the lack of reliable data, evidence on economic development in Africa has mostly been anecdotal, and, although the last decade has witnessed a proliferation of possible explanatory variables, there is little guidance from economic theory regarding which variables to include in growth regressions. In addition, informed opinion is sharply divided over whether Africa grows differently enough to warrant an Africa-only theory of growth or whether African economic development can be explained within the global context.

A number of recent studies have argued that determinants of growth in Africa are the same as elsewhere, so that Africa's slow growth should be explained in terms of lower mean levels of growth enhancing factors and relatively higher mean levels of growth retarding factors (Sachs and Warner 1995, 1997; Barro, 1991; Easterly and Levine, 1999). As a result, in much of the empirical literature on economic growth, sub-Saharan Africa exists primarily as a regional dummy (Barro and Lee, 1993; Easterly and Levine, 1997; Collier and Gunning, 1999; Sala-i-Martin, 1997; Sachs and Warner, 1997, just to mention a few). These studies use a near-global sample of countries, imposing the same specification for all regions except for the inclusion of regional dummies as level variables or interaction effects. Therefore, if this approach is correct, African growth is explained by the differences between Africa and the other regions in the standard explanatory variables, in which case the African dummy will be statistically insignificant (Collier and Gunning, 1999).

In this paper we explicitly investigate the determinants of economic growth in Africa using a Bayesian model framework. This framework allows us to do two things. First, it allows us to investigate the issue of model uncertainty in African growth regressions by estimating the posterior probabilities of all possible explanatory variables commonly used in cross-country growth regressions for which data are available. Second, we attempt to identify the factors explaining differences in growth by allowing for any subset of these variables to combine in a growth regression and estimate the implied posterior probability of any such combination of regressors. This work contributes to the growth literature in two ways. First, by comparing the posterior probability of different variables in the global and Africa-only sample, we explicitly test whether Africa grows differently. Second, based on formal statistical inference, we can show which combination of variables best explains cross-country growth in Africa.

The remainder of this paper is organized as follows. Section 3.2 reviews the theoretical and empirical literature while section 3.3 gives a brief overview of the Bayesian Model Averaging framework (henceforth, BMA). Section 3.4 describes the data and discusses the results obtained from our estimation and robustness checks. Section 3.5 concludes.

3.2 Theoretical and Empirical Literature

In the growth literature there are three main hypotheses on the determinants of Africa's slow growth. These are the geographical/endowment hypothesis, the institutional hypothesis and the policy hypothesis.

3.2.1 Geography/Endowment Hypothesis

Traditionally, Africa's slower growth has been explained in terms of the geographical hypothesis. In general, geography and the environment shapes economic development directly by influencing both the inputs into the production function and the production function itself (Easterly and Levine, 2002). In the African context, although individual countries differ in location and topography, in general Sub-Saharan Africa is distinct with respect to tropical climate, location and comparative advantage. According to this view, there appears to be a positive correlation between tropical climate and underdevelopment (Collier and Gunning, 1999). However, the transmission mechanism from tropical climate to underdevelopment has never been clear cut because geography/endowment can have positive or negative effects on economic growth.

On the one hand, a country that is large in area is likely to have diverse natural resources which can positively contribute towards economic growth (Hagen, 1986). In addition, the more valuable a country's natural resources are, in the aggregate and per capita terms, the more readily it can gain high value of output per worker and in turn high income per capita.[1] On the other hand, countries that are small in area and population and limited in the variety of resources, like most Sub-Sahara African countries, will be retarded by size of their markets unless they can specialize and sell in international markets.

[1]It is worth noting that 9 of the world's 14 so-called mineral-based economies are in Africa and most fall into the low income group.

However, the most dominant geography/endowment view has been fortified by recent contributions by Sachs and Warner (1995, 1997) who suggest that tropical location, landlocked location and reliance on a narrow range of commodity exports directly inhibit growth. Tropical climate is inimical to African growth and development because much of the continent is semi-arid, which raises the fragility of soils, leaches nutrients from the soils when it rains and leads to a high prevalence of crop pests and diseases, making agricultural production intrinsically risky. In addition, a tropical climate enervates and increases the prevalence of infectious diseases for humans, especially malaria and bilharzia (Landes, 1998).

Although abundance of natural resources is often cited as a redeeming feature of Africa's geography and a source of comparative advantage in natural resources exports, export concentration in natural resources has also meant that African terms of trade remain ransomed to the capriciousness of international commodity prices. Since in the past thirty years international prices for primary commodities have been declining relative to prices of manufacturers from developed nations, African gross and net barter terms of trade for primary commodities have been volatile which, in turn, has had long term effects on output. This is compounded by the fact that 33 percent of African countries are landlocked (have no sea ports), in contrast to only 11 percent of countries classified as less developed on other continents. This raises the cost of international trade and renders exports from landlocked nations internationally uncompetitive. Being landlocked also increases the domestic cost of living through imported inflation. On average the landed value of imports is higher in landlocked countries than in countries with access to the sea (Sachs and Warner, 1997). Therefore, in countries where all equipment and spare parts have to be imported, geography imposes extra costs on investment which reduces the rate of return on investment and in turn, economic growth.

3.2.2 Institutional Hypothesis

The second hypothesis argues that institutional quality is a fundamental determinant of economic development (Acemoglu, Johnson and Robinson, 2001; henceforth AJR). According to this view, while the environment, geography and endowments are important for growth, they only affect economic development through long-lasting institutions (Easterly and Levine, 2002). That is, an environment in which major cash-crops are produced using large plantations, inevitably leads to development of political and legal institutions which protect the interests of a few land holders from the many peasants. However, the pathways through which institutions affect economic development are not clear cut.

The "tropics" theory of the institutions is based on the view that since Western European countries have historically been associated with strong institutions, countries with climates similar to western Europe will have significant numbers of European settlers and in turn develop better institutions. Africa, with its predominantly tropical climate, was less likely to attract European settlers and, therefore, will have low quality institutions (Hall and Jones, 1999).

In contrast, AJR use a "germs" theory of institutions. First, they acknowledge that institutional quality indeed depends on European colonization. However, their point of departure is that European colonial settlement and institutional development was a function more of germs than mere location. That is, where the germs were favorable for European settlement (e.g. the USA, Australia, New Zealand), they established settler colonies and created institutions that supported private property and checked the power of the state. However, in areas where germs created high settler mortality, Europeans, by force of arms or in collusion with traditional elites, tended to create extractive colonies. In the latter case, Europeans did not create institutions that supported private property, but instead they established institutions that empowered the elite to extract minerals and valuable commodities.[2] Since the legacy of these institutions endured after independence, settler colonies tended to produce post-colonial governments that were democratic and more devoted to defending property rights. In contrast since extractive colonies had already created institutions for effectively extracting resources, the post-colonial elites frequently assumed power and exploited the pre-existing extractive institutions (Easterly and Levine, 2002).

The persistence of these extractive institutions in post-colonial Africa has also affected long-term economic growth by increasing the rate of return to rent-seeking behavior and by raising the probability of corrupt practices (Murphy, 1991). The existence of increasing returns to rent-seeking behavior, in turn, may crowd out productive investment, since corruption in effect imposes a tax on ex-post profits (Murphy, 1991). In addition, since most African governments have permitted a low level of civil and political liberties, in general Africa is lacking in public social capital, especially the institutions of government that ensure good governance, accountability and facilitate private activity, such as courts, independent regulatory and financial institutions (Collier and Gunning, 1999).

3.2.3 Policy Hypothesis

The third hypothesis, beloved of the World Bank and IMF, is the policy hypothesis. This view holds that economic polices and institutions reflect current knowledge and political forces (Easterly and Levine, 2002). Changes in either current knowledge about which policies and institutions are best for development or changes in political incentives will produce rapid changes in institutions and economic policies. This hypothesis first discounts the role of geography/endowment and institutional variables by asserting that although tropical environment, disease and colonial

[2] The development of plantation agriculture both in South America and Africa, and granting of mineral rights to European mining corporations both in South America and Africa are cases in point. This stands in stark contrast to South Africa, whose climate is predominantly meditteranean, and its germs and climate were relatively more forgiving to European settlement than those of tropical Africa.

legacy may influence production and institutions, understanding environmental and institutional forces is not crucial to understanding economic development.

In the post-colonial era, two important developments came into play in Africa. First was the creation of new monopolies which extended the role of the state in entrepreneurship. The main justification of state intervention in the market was a desire to promote industrialization and economic growth. It was argued that the interest of the private investor who dominated the colonial economy could scarcely be expected to be entirely harmonious with national needs of development (Ake, 1985). In addition, it was necessary to encourage development of enterprises controlled by nationals which could compete with, and if possible, displace those owned and controlled by foreign capital. Since the discriminatory practices of the colonial regimes had made it difficult for nationals to accumulate any wealth, so the argument went, there was really not much choice for the state but to play the role of the entrepreneur, and undertake investment on behalf of the people. Although these state enterprises were funded from government funds, in the most extreme cases state enterprise came into life due to nationalization of foreign owned private enterprises.

However, economic participation of state enterprises became distortionary to both internal and external balances. In most countries, the government created state marketing monopsonies that acted as intermediate traders between local farmers and international markets and undermined efficiency in product markets by abolishing competition and by the use of price and quantity controls. In addition, due to low levels of financial development, the cost of financial information in Africa is unusually high and African economies are characterized by a lack of financial depth. These costs are further compounded by policy generated costs including implicit taxes through financial repression, unremunerated reserve requirements, credit rationing and preferential allocation of credit to the public sector, which crowds out private investment.

Second, was the restriction of international trade which had inhibiting consequences for economic development in general and growth in particular. Notice that most state enterprises were created as a means to promote exports and realize import substitutions. Using the infant industry argument, parastatal enterprises were granted monopoly privileges to help them survive in the short run and eventually become competitive and even profitable in the long term. To this end, African governments imposed taxes on international trade on which they increasingly became reliant for revenues and also imposed implicit taxes through exchange rate overvaluation. The combination of state intervention in domestic markets, restrictive international trade policy and poor public services has cumulatively contributed to a capital-hostile environment that has reduced the rate of return on investment and kept out foreign investment.

3.2.4 Empirical Evidence

How Africa is treated in the empirical literature depends on which hypothesis underlies the study. In studies that investigate the applicability of the geography/endowment hypothesis, Africa exists primarily as a regional dummy. In this case, African growth is explained if it is fully accounted for by the differences between Africa and the other regions in the standard explanatory variables, in which case the African dummy will be statistically insignificant (Collier and Gunning, 1999). In other studies, the geography/endowment hypothesis is tested using absolute latitude as proxy for tropical location, access to the sea, initial conditions and measures of natural resources endowment.

So far, the evidence on the geography/endowment hypothesis (proxied by a sub Saharan Africa dummy) has been mixed. While Barro and Lee (1993) and Easterly and Levine (1999) find the African dummy to be both large and significant, Collier and Gunning (1999) find the African dummy significant only when interacted with investment and the degree of openness but insignificant when interacted with other explanatory variables. Temple (1998) eliminates the African dummy all together while Sachs and Warner (1997) find a significant tropics dummy in its stead. In addition, Sachs and Warner (1997) also find that being land-locked and having the Dutch disease account for a significant fraction of Africa's growth shortfall while Barro and Lee (1993) and Sala-i-Martin (1997) also find tropical location (proxied by absolute latitude) to be significant in growth regressions. Notice, however, that in these studies the underlying assertion is that Africa is not different from other regions with regard to factors contributing to growth. It is argued that Africa's slow growth is, therefore, partly explicable in terms of particular variables that are globally important for the growth process but are low in Africa (Sachs and Warner, 1997; Rodrick, 1998). The emerging evidence, however, suggests that the determinants of growth, their marginal impacts on growth and the transmission mechanism through which those factors affect growth are different in Africa (Block, 2001), thereby pointing to the need for an Africa-only theory of growth.

The evidence on the institutional hypothesis is equally mixed. Although the dominant view is that Africa's slow growth can be explained in terms of variables measuring the political and legal environment and institutions, there is no consensus on how to measure institutional quality. While Easterly and Levine (1999) use ethnolinguistic fractionalization and number of assassinations, Sachs and Warner (1997) proxy institutional quality with measures of openness. Similarly, Barro and Lee (1993) measure institutional quality by the number of revolutions while Collier and Gunning (1999) use degree of openness and number of months a country was engaged in civil wars. In a recent contribution, Block (2001) models institutional quality as a function of ethnolinguistic fractionalization, initial total years of schooling of the over 25 population and the share of raw materials in total exports while Bates (2001) measures institutional quality by an index that combines measures of civil and political freedoms, quality of bureaucracy and the degree of popular participation in electing people into executive office.

The actual impacts of institutional variables in growth regressions have equally been mixed. Easterly and Levine (1999) find that ethnolinguistic fractionalization has a negative impact on growth, directly accounting for 35 percent of Africa's growth shortfall. However, Collier and Gunning (1999) contend that although ethnic diversity has indeed been costly to Africa, this is because of the low level of political rights. Due to high correlation between ethnic diversity and poor polices, in countries with full democratic rights diversity appears to have no detrimental effect on growth (Collier, 1998). In contrast, Bates (2000) even finds that ethnic diversity actually promotes the formation of human capital by providing the political structures that render credible implicit inter-generational contracts. Moreover, Mauro (1995) finds weak support for a direct relationship between corruption and growth. Although, Poirson (1998) and Rama (1993) find that corruption has a significant negative effect on economic growth, Leite and Weidman (1999) make two findings which are exculpatory to Africa. First, they note that corruption is not inherently affected by ethnic diversity. In addition, they find that the growth effects of corruption seem to be the same in Africa as elsewhere.

The evidence on the policy hypothesis appears more conclusive than on geography and institutions, although there are differences on measures of policy. The most common measure of the stance of economic policy is *openness*, although there is little consensus on how it should be measured. Sachs and Warner (1997) use market access, access to the sea and their own index, while Easterly and Levine (1999) use black market premium and others use real exchange rate misalignment as proxies. Not withstanding differences in measures and variation in magnitudes of marginal impacts, the evidence on direction of impact of openness is unanimous. While Block (2001) optimistically argues that economic liberalization and more openness in Africa would increase per capita output growth by 4.1 percent annually, Sachs and Warner (1997) find that the combination of restrictive trade policy, being land-locked and having the Dutch disease account for 1.2 percent of Africa's growth shortfall while Easterly and Levine (1999) suggest a much lower estimate (0.4 percent). Collier and

Gunning (1999) also find that a given level of trade restrictions is half as damaging in Africa as in other less developed countries.

The evidence regarding other policy variables is equally mixed. Although low education, black market premia and lack of financial depth are associated with low growth (Easterly and Levine, 1999), the overall effect appears to be modest (Collier and Gunning, 1999). In addition, an increase in the ratio of private investment to GDP appears to have a larger positive effect on growth than an increase in the ratio of public investment to GDP (Calamitsis et al. 1999). Sachs and Warner (1997) conclude that poor policies and institutions explain a large share of Africa's slow growth and that better policies would contribute to stronger economic performance.

In a nutshell, there is a broad consensus in the growth literature that although Africa is relatively lacking in many socio-political indicators, and while these variables have been found to be significant in growth regressions, there is no evidence that their effect in Africa is different from the rest of the world. In fact, Block concludes that in Africa's case, statistically significant differences between Africa and the rest of the world may not be necessarily quantitatively important in explaining Africa's slower growth. He finds that although slope coefficients for African interaction terms for initial income, life expectancy, institutional quality and population growth are neither singly nor jointly significantly different from the non-African slopes, in each case African differences in the levels of these determinants seem to undermine growth.[3] In short, Africa seems unable to benefit from particular factors that are associated with rapid economic growth in the broader cross-section of countries.

In much of the growth literature the evidence reviewed thus far is derived using Barro-type cross-country regression equations (see Barro, 1991; Mankiw et al., 1992 and the subsequent literature). Unfortunately, due to the proliferation of possible explanatory variables in cross-country regressions and the relative lack of guidance

[3]Block (2001) employs t-tests to establish that differences in the means of growth determinants between Africa and non-Africa are statistically significant.

from economic theory as to which variables to include, a number of problems have plagued the robustness of these cross-country regressions, not the least being model uncertainty (Durlauf, 2001; Block and Durlauf , 2001; Temple, 1999). Levine and Renelt (1992) investigate the robustness of cross-country regressions using extreme bounds analysis and find that few variables pass the test. In contrast, Sala-i-Martin (1997) using a less restrictive test identifies a relatively large number of variables to which he assigns some level of confidence for inclusion in growth regressions. These authors restrict the set of regressors to always contain certain key variables and then allow for four other variables to be added.

Fernandez, Ley and Steel (2001a) (henceforth FLS) offer an alternative approach by allowing for any subset of regressors to appear in the model using a BMA framework. The BMA framework allows empirical investigation of both model and parameter uncertainty using formal statistical inference. Rather than selecting a single model, in BMA all inference is averaged over models using the corresponding posterior model probability as weights, thereby identifying both the variables and models that would be useful for growth regressions.[4]

3.3 Model

Our model follows FLS. We consider n independent replications from a linear regression model where the dependent variable, GDP growth in n countries grouped in vector y, is regressed on an intercept α and a number of explanatory variables chosen from a set of k variables in a design matrix Z of dimension n x k. Assume that $r(\iota_n : Z) = k+1$ where $r(\cdot)$ indicates the rank of a matrix and ι_n is an n-dimensional vector of 1's. Further define β as the full k-dimensional vector of regression coefficients.

[4]For a complete discussion of BMA see FLS.

Now suppose we have an $n \times k_j$ submatrix of variables in Z denoted by Z_j. Then denote by M_j the model with regressors grouped in Z_j, such that

$$y = \alpha \iota_n + Z_j \beta_j + \sigma \varepsilon \tag{3.1}$$

where $B_j \in \Re^{k_j}$ $(0 \leq k_j \leq k)$ groups regression coefficients corresponding to the submatrix Z_j, $\sigma \in \Re_+$ is a scale parameter and ε is assumed to follow an n-dimensional normal distribution with zero mean and identity covariance matrix. In addition, exclusion of a regressor in a particular model implies that the corresponding element of β is zero. Notice that if we allow for any subset of variables in Z to appear in the model, this gives rise to 2^k possible sampling models depending on whether we include or exclude each of the regressors.

To complete this sampling model, we need to specify a prior distribution for all models in the model space, and the models and parameters in M_j, namely α, β_j and σ. While inclusion of prior information is a distinguishing feature of the Bayesian approach to inference, when prior knowledge about a parameter is vague or diffuse, then Bayesian analysis with non-informative prior is suitable (Judge et al., 1988). In this work, since prior knowledge about the parameters for Africa is lacking, incorporating prior information is neither feasible nor desirable, so we need a benchmark prior distribution that will have little influence on posterior inference. This represents an improper non-informative prior for the parameters that are common to all models and a g-prior structure for β_j which corresponds to the product of

$$p\,(\alpha, \sigma)\, \sigma^{-1} \tag{3.2}$$

and

$$p\,(\beta_j | \alpha, \sigma, M_j) = f_N^{k_j}\left(\beta_j | 0, \sigma^2 (g Z_j' Z_j)^{-1}\right) \tag{3.3}$$

where $f_N^q(w|m, V)$ denotes the density function of a q-dimensional normal distribution on w with mean m and covariance matrix V and $g = 1/\max\{n, k^2\}$. In this case the $k - k_j$ components of β which do not appear in M_j are set exactly equal to zero.

Notice that the distribution in equation (3.2) is the standard non-informative prior for location and scale parameters which is invariant to location and scale transformations.

In addition to the prior distribution of the subset, M_j, due to uncertainty about choice of regressors, there is a need to specify the sampling and prior distribution over the space $\mathcal{M}$ of all 2^k possible models:

$$P(M_j) = p_j, \qquad j = 1, ..., 2^k, \quad \text{with } p_j > 0 \text{ and } \sum_{j=1}^{2^k} p_j = 1 \tag{3.4}$$

Since we lack substantive prior information it is assumed that $p_j = 2^{-k}$ so that we have a uniform distribution on the model space, with the prior probability of including any regressor equal to $\frac{1}{2}$ and independent of the other regressors in the model. Given this set up, the notion of BMA implies that the posterior probability of any given parameter of interest which has common interpretation across models, say Δ, is the weighted posterior distribution of that quantity under each of the models with weights given by the posterior model probabilities, so that

$$P_{\Delta|y} = \sum_{j=1}^{2^k} P_{\Delta|y,M_j} P(M_j|\, y) \tag{3.5}$$

That is, the marginal posterior probability of including certain variable is the sum of the posterior probabilities of all models that contain a regressor. The posterior model probability is

$$P(M_j|y) = \frac{l_y(M_j)p_j}{\sum_{h=1}^{2^k} l_y(M_h)p_h} \tag{3.6}$$

where $l_y(M_j)$, is the marginal likelihood of model M_j given by

$$l_y(M_j) = \int p\,(y|\alpha, \beta_j, \sigma, M_j)\, p(\alpha, \sigma) p(\beta_j|\alpha, \sigma, M_j) d\alpha d\beta_j d\sigma \tag{3.7}$$

where $p\,(y|\alpha, \beta_j, \sigma, M_j)$ is the sampling model corresponding to equation (4.1), $p(\alpha, \sigma)$ and $p(\beta_j|\alpha, \sigma, M_j)$ are the priors defined in equations (3.2) and (3.3) respectively.

In our application we begin with $k = 26$ possible regressors, which implies that we need to calculate posterior probabilities for 2^{26} models and average the required distributions over these models. However, following Fernandez et. al. (2001b), we approximate the posterior distribution on the model space $\mathcal{M}$ by simulating a sample using a Markov chain Monte Carlo model composition sampler. For the set of models visited by the chain, posterior probabilities will be computed by normalization of equation of $l_y(M_j)\,p_j$. In addition, a high positive correlation between posterior model probabilities based on empirical frequencies of visits in the chain and the exact marginal likelihoods suggests that the model has reached its equilibrium distribution (FLS).

3.4 Data, Estimation and Results

3.4.1 Data

We use a subset of the data used by Sala-i-Martin (1997) covering 37 sub-Saharan African countries for which average GDP growth was averaged over 1960-1992. We chose the Sala-i-Martin dataset because it covers 42 African countries of which 37 are Sub-Saharan.[5] However, due to lack of data in this dataset for equipment and non-equipment investment for most African countries, we used Summers and Heston's investment measure (see appendix C, Tables C1 and C2 for a list of countries and data sources used in this paper, respectively).[6]

Table 3.1 shows the variables that will be used in our basic estimation. These variables have been used extensively in cross-country growth regressions and have been found to be significant in global regressions. These descriptives are based on data covering 1960-1992. For each country GDP growth is measured as the annual percentage change in the natural logarithm of GDP per person between 1960 and 1990 from Summers and Heston's (1988) purchasing power parity adjusted in chained

[5] In constructing their dataset FLS exclude most Sub-Sahara African countries due to data unavailability for their chosen time horizon and end up including only 19 Sub-Sahara African countries in their whole sample of 72 countries.

[6] This should not alter our results qualitatively. Sala-i-Martin finds that substituting the investment share of GDP with equipment and non-equipment investment does not critically alter their model's qualitative implications.

dollars. Over this period, African growth averaged 0.4 percent while the global growth average 2.07 percent.

We include the following variables as regressors. First, following convention in the literature, we include initial output in 1960, measured by the log of real per capita output in 1960, to capture the convergence effect (Mankiw, Romer and Weil, 1992). Initial output is expected to have a negative sign, reflecting the convergence effect, in growth regressions. We also include three other measures of initial conditions. Primary schooling measures the average years of primary schooling in the total population aged 25 and over in 1960 and is expected to be positively related to growth. Life expectancy at birth in 1960 is included to capture the initial stock of human capital. It is expected to have a positive effect on growth.

Table 3.1 shows that in 1960, the level of GDP in Africa was half as much the level of GDP in the rest of the world, life expectancy at birth was only 40 years in Africa compared to 61 years in the world. Whereas 89 percent of the world's primary-school age population was enrolled in school, only 41 percent of the corresponding population in Africa was enrolled in primary school.

In addition, the fraction of primary commodities in exports in 1970 is included as a measure of the initial level of economic development. The fraction of primary commodities in exports is negatively related to growth (Sala-i-Martin, 1997). While primary commodities comprise 65 precent of exports in the rest of the world, in Africa they account for 88 percent of the exports. We also include a special type of primary commodity, mineral exports, proxied by the fraction of mining in GDP. The share of mining is expected to have a negative effect on growth.

We also include a number of geography/endowment factors. First, we include the absolute latitude as a proxy for tropics. Table 3.1 shows that the majority of African countries are in the tropics. Latitude is expected to be positively correlated with growth. Sachs and Warner (1997) point out that countries that are closer to the equator have a more tropical climate, which is inimical to growth due to a

Table 3.1: Data and descriptives

	Regressor	Rest of World	Africa
1	ln GDP level in 1960	8.376	6.63
2	Fraction of Mining in GDP	0.026	0.072
3	Primary Exports, 1970	0.605	0.884
4	Primary School Enrolment, 1960	0.892	0.409
5	Life Expectancy, 1960	60.746	40.900
6	Investment	0.210	0.092
7	Number of Years Economy open	0.545	0.083
8	Outward Orientation	0.326	0.432
9	Exchange Rate Distortion	106.7	161.6
10	Economic Organization	3.788	3.000
11	Population Growth	0.018	0.027
12	French Colony Dummy	0.038	0.378
13	British Colony Dummy	0.250	0.432
14	English Speaking Fraction	0.103	0.005
15	Fraction Speaking Foreign language	0.449	0.064
16	Ethnolinguistic Fractionalization	0.272	0.649
17	Revolutions and Coups	0.178	0.268
18	War Dummy	0.403	0.405
19	Political Rights	2.767	5.689
20	Civil Liberties	2.840	5.438
21	Absolute Latitude	29.678	10.71
22	Fraction Protestant	0.174	0.157
23	Fraction Muslim	0.077	0.299
24	Fraction Catholic	0.522	0.197
25	Area (Scale Effect)	1097.615	624.4

high prevalence of animal and human diseases. AJR and Easterly and Levine (2001) suggest that a tropical climate also signals the likelihood of extractive institutions being a significant element in the economy. Second we include a measure for a country's land area to capture scale effects. On average, African countries are smaller than countries on other continents so that we can conjecture that it would be more difficult for African nations to take advantage of scale economies. In addition, Africa has other natural disadvantages. In Africa 33 percent of countries have no access to the sea, in contrast to 11 percent of all countries in the rest of the world.

There are a number of measures of political institutional quality that are included. The *rule of law index* reflects the degree to which a country's citizens are willing to accept established institutions to make and implement laws. It's a measure of protection of persons and property against violence or theft, and an independent and effective judicial system. In addition, *Political rights* index measures the extent to which citizens can choose their government and *civil liberties index*, captures the extent to which freedom of the press prevails.[7] Institutional quality is expected to be positively correlated to economic development and better endowments (Easterly and Levine, 2002). We also include variables that reflect behavior disruptive to the pursuit of economic growth. These include a *War dummy*, which equals one if the country has participated in any external war and *Revolutions and coups* which is the number of times there was a change in executive office-holders through unconstitutional or violent means. The evidence shows that African citizens enjoyed a lower level of political rights and civil liberties than did the rest of the world.

The institutional literature has also emphasized the role of colonialism in fostering strong institutions. We therefore include dummies for British and French colonial ties, and the fraction of the population that can speak either English or any foreign language. While 43 and 37 percent of African countries are former British

[7] Sachs and Warner's (1997) institutional index combines the rule of law index, bureaucratic quality index, corruption in government index, risk of expropriation index and likelihood of government repudiation of contracts.

and French colonies, respectively, only 0.5 percent of the African population speaks English and only 6 percent speaks any European language. We also include a measure of ethnolinguistic diversity following Easterly and Levine (1997) who suggested that there is a negative relationship between diversity and growth. Ethnolinguistic diversity measures the probability that two randomly selected individuals from one country belong to different ethnolinguistic groups. However, there is no unity of local languages either. There is a 64 percent chance that two randomly selected Africans belong to different ethnolinguistic groups, compared to 37 percent for the rest of the world.

A number of economic institutional variables are included: *viz*, the real exchange rate misalignment, the number of years the economy has been open, the scale of outward orientation (dummy equal one if has country leans socialist), and a measure for the organization of the economy (degree of capitalism). Over the 1960-1992 period, Africa appears to have performed worse in the economic institutional domain than did the rest of the world. On average, African countries had been open for 8 percent of the entire period in contrast to the world which had been open for 43 percent of the 32 years. Consequently, Africa is characterized by a lower degree of capitalism and higher average real exchange rate distortion than the rest of the whole world. We also considered financial market variables. However, due to the paucity of data on Africa, available measures of financial development entailed considerable loss of observations. Such variables included measures of financial depth, the ratio of liquid liabilities to GDP and measures of money supply (M1 or M2).

Finally, we include different measures of religion as alternative proxies for social institutions. We include the fraction of the population that is Catholic, Protestant and Muslim to capture this effect. Table 3.1 shows that 19 percent of the African population was Catholic, 30 percent was Muslim and 16 percent was protestant. Thus the majority followed traditional religions.

In this paper we use a subset of $k = 26$ regressors from the Sala-i-Martin dataset which did not entail substantial loss of observations. We have available $n = 37$ observations for all these regressors so that Z will be a 37×26 design matrix corresponding to these variables, and we shall allow for any subset of these 26 regressors giving a total of 2^{26} possible models under consideration in $\mathcal{M}$. We use the Bayesian model presented in equations $(1-4)$ with a uniform prior on model probabilities ($p_j = 2^{-k}$). In addition, since $n < k^2$, we use $g = 1/k^2$ as the prior (see FLS).

In order to answer if Africa grows differently, we compare the results derived from the Africa-only sample with those obtained by FLS using a global sample of 72 countries. Notice that by concentrating on Africa, a number of variables relevant in a global context were excluded, either due to data unavailability or irrelevance of the variable to Africa. Variables not relevant for Africa included regional dummies for Latin America and Spanish colonial influence, fraction of the population Confucian, Buddhist, Hindu and Jewish.

3.5 Results

The results reported are based on a run with one million recorded drawings after a burn-in of 100,000 discarded drawings. As a diagnostic, we note that the model performance is satisfactory, evidenced by the high correlation coefficient between visit frequencies and posterior probabilities of 0.991. In addition, due to our choice of the improper uninformative prior, the prior has little effect on posterior model probabilities. Although 32,996 models were visited, the prior probability for a single model is 0.14E-05 percent. Consequently when we estimate the posterior probabilities, the total posterior mass is spread out with 5,010 models accounting for 90 percent of the posterior mass. However, the cumulative posterior probability of the best 132 models, those with posterior probabilities greater than 0.10 percent, is 44 percent of total posterior mass.

Since the posterior mass is spread out, this necessitated Bayesian Model Averaging using equation (3.6). This methodology not only provides information on which combinations of regressors are more likely to occur, thereby avoiding models with collinear regressors, but also the Bayes factor obtained in equation (3.6) has a built-in mechanism to avoid overfitting (FLS). This improved the model performance because, although 13,043 models were now visited, just 2,422 of them accounted for over 90 percent of the posterior model probability. Moreover, the 142 models with posterior probability greater than 0.10 percent accounted for 50.27 percent of the posterior mass and, while the model ranking is identical, the posterior model probability rises when we averaged over the models. The model gives two sets of result: regressor and model posterior probabilities.

3.5.1 Posterior Regressor Probabilities

The first exercise involves analyzing the importance of each regressor by looking at the individual regressor's posterior probability. This is especially important for cross-country growth in two contexts. First, is the issue of model uncertainty. Some regressors tend to be significant in growth regression only in combination with some particular regressors but lose their power when these regressors are excluded. Due to this model uncertainty, we need some guidance regarding variables which have high posterior probability and ought to be included in growth regressions, based on solid statistical inference. Second, if the assertion that factors governing growth in Africa and elsewhere are the same is valid, then the posterior probabilities and relative importance of the regressors in the global sample should be the same as in an Africa-only sample.

Table 3.2 compares the marginal importance of regressors derived from the BMA methodology on an Africa-only sample and the FLS sample of 72 countries. The regressors have been sorted in descending order of the posterior probabilities in the Africa-only sample. Although the posterior probability of these regressors varies from 1.7 percent to 100 percent in the near-global sample, in the African sample, the posterior probabilities vary from as low as 21 percent to 99.3 percent. In general, notice that except for the level of output in 1960 which measures the convergence effect, regressors that have high posterior probability (above 0.90) in the global sample lose their explanatory power in the Africa-only sample.

These results highlight the role of initial conditions and institutions on African growth. In the Africa-only sample, three of the four variables with highest posterior probability reflect the initial level of economic development (GDP 1960 and fraction of primary commodities in exports in 1970) and initial stock of human capital (primary school enrollment in 1960). However, the fourth variable, the fraction of mining in GDP, is a measure of natural resource endowments.

3.5.2 Posterior Model Probabilities

Although ranking posterior probability is informative about relative importance of regressors, model uncertainty often occurs in combination with regresssors. As such we need to investigate the combination of regressors that best explains the observed growth in per capita output. Table 3.3 shows the best three models and the associated posterior probabilities in the Africa-only and global samples. In the Africa context, although the models reported have a maximum of five variables, the full set of models ranges between three and seven regressors, which accords with Sala-i-Martin's (1997) suggestion that the optimal number of regressors in growth regressions is seven. Given our set of 26 regressors, the best model has a posterior probability of 4.82 percent. The subset of regressors with the single highest posterior explanatory probability is one that includes GDP60, the number of years the economy has been open, the share of primary commodities in exports and the ratio of investment to GDP. Unlike in the individual regressors, three of the variables in the best model reflect economic institutions.

Table 3.2: Posterior probabilities of regressors

	Regressor	**Global Sample**	**Africa Sample**
1	GDP level in 1960	1.0000	0.993
2	Fraction of Mining in GDP	0.441	0.944
3	Primary Exports, 1970	0.071	0.921
4	Primary School Enrollment, 1960	0.184	0.719
5	Investment	0.942	0.631
6	Number of Years Economy open	0.502	0.593
7	Fraction Protestant	0.461	0.553
8	Outward Orientation	0.021	0.546
9	British Colony Dummy	0.022	0.541
10	Revolutions and Coups	0.017	0.472
11	Fraction Muslim	0.656	0.469
12	Life Expectancy, 1960	0.946	0.416
13	English Speaking Fraction	0.047	0.415
14	Area (Scale Effect)	0.016	0.391
15	Ethnolinguistic Fractionalization	0.035	0.390
16	Economic Organization	0.478	0.334
17	Fraction Speaking Foreign language	0.047	0.285
18	Fraction of Population Urban,1960		0.276
19	Population Growth	0.022	0.274
20	War Dummy	0.052	0.250
21	Political Rights	0.069	0.235
22	Absolute Latitude	0.024	0.233
23	French Colony Dummy	0.031	0.229
24	Exchange Rate Distortion	0.060	0.222
25	Fraction Catholic	0.110	0.219
26	Civil Liberties	0.100	0.216

Table 3.3: Model posterior probabilities

Model	Regressors	Post. Prob. (%)
	Africa-Only Sample	
1	GDP60, Yrs Open, Primexp70, Invest	4.82
2	GDP60, Yrs Open, Mining, Primexp70, Invest	3.65
3	GDP60, Yrs Open, Revcoup, Mining	2.22
	Global Sample	
1	GDP60, Ecorg, Lifexp, Invest, SubSahara, Confucious, Muslim, Protestant, Rule of Law	2.85
2	GDP60, Ecorg, Lifexp, Invest, SubSahara, Confucious, Muslim, Rule of Law	2.49
3	GDP60, Lifexp, Invest, SubSahara, Yrs Open, Confucious, Muslim, Mining	1.66

In contrast, in the global sample, models range from six to twelve regressors (see FLS). The best model in the global context has a posterior probability of 1.87 percent and comprises ten variables which include life expectancy, level of GDP in 1960, the type of economic organization, rates of equipment and non-equipment investment, a Sub-Saharan Africa dummy, the fractions of the population that is Confucious, Muslim and Protestant and the rule of law. As we show below, not only are the models with the highest posterior probability in Africa different from the rest of the world, but implied impacts in growth regressions are equally diverse.

The union of the ten best models broadly suggests that in the African context, growth can be explained primarily by a combination of economic institutional variables (level of initial output, the number of years the economy has been open to international trade, the share of primary commodities in exports and the share of investment in GDP) and geographical/endowment variable (fraction of mining). However, measures of political institutions, like the rule of law, civil liberties and political rights do not enter the models with high posterior probability. Unlike in the global set, religion does not enter as a factor in growth models for Africa.

Table 3.4: Regressions results of models implied by Africa-only and Global samples.

Specification	Best Models		Second Best	
	Africa-Only	Global Model	Africa-Only	Global Model
Constant	12.118*** (2.808)	0.822 (4.136)	11.418*** (2.636)	0.814 (4.042)
Years Open	4.844*** (0.967)	—	4.857*** (0.903)	—
Primary Exports	−4.139*** (1.208)	—	−3.448*** (1.162)	—
GDP60	−1.477*** (0.350)	−0.942* (0.492)	−1.458*** (0.326)	−0.942* (0.481)
Investment	0.136*** (0.030)	0.093* (0.047)	0.100*** (0.032)	0.094* (0.046)
Mining	—	—	4.150*** (1.707)	—
Life Expectancy	—	0.075 (0.074)	—	0.077 (0.071)
Economic Org	—	0.210 (0.134)	—	0.214 (0.127)
Muslim	—	0.094 (1.020)	—	0.023 (0.867)
Protestant	—	0.328 (2.346)	—	—
Rule of Law	—	2.846** 1.220	—	2.825** (1.183)
Adj. R^2	0.583	0.302	0.638	0.333
Obs.	32	31	32	31

Notes: *** Significantly different from 0 at the 1% level. ** Significantly different from 0 at the 5% level. * Significantly different from 0 at the 10% level.

We also estimated the two best models implied by the Africa-only and global samples. Table 3.4 shows that all variables chosen by the Africa-only models are significant at the 1 % level. As expected, coefficients associated with GDP60 and primary exports have negative signs while coefficients for the share of investment and mining in GDP and the number of years the economy has been open are positive. In contrast, if we assume that determinants of growth in Africa and the rest of the world are the same and use variables chosen by the global model, then only three regressors are statistically significant, albeit at low marginal significance levels.

In addition, these results also illustrate that models chosen by the procedure are more superior to those chosen subjectively. Second, some variables whose posterior probability is high in the Africa-only sample lose their explanatory power if combined with variables whose posterior probability is not established by the procedure. This is true for investment share of GDP and GDP60 which are significant at the 1 % level in the Africa-only based model but lose significance to 10 % when combined with regressors implied by the globally-relevant model.

The issue then is, why are these variables, or combinations thereof, more important in explaining African growth than global growth? As a collolary, why are other variables which are globally important not relevant in explaining African growth? We do not discuss the implication of the level of GDP in 1960 since it has the same meaning and significance in the global and Africa-only samples.

First, the fact that mining has relatively higher posterior probabilities in Africa than elsewhere should come as no surprise. Although mining has a positive effect on economic growth, the dominance of mining in GDP has been a double-edged blessing for Africa. Africa's all-time fastest growing economy, Botswana, is dependent on exports of diamonds. Similarly, Africa's fastest growing economy in the 1990s, Equatorial Guinea, owes its growth to oil drilling which began in earnest in early 1990 (UNCTAD, 2002). However, for the most part, reliance on mining is more pertinent in explaining Africa's slow growth. Heavy reliance on mining has rendered many mineral-dependent economies vulnerable to changes in global demand. African star performers of the 60s and 70s experienced a reversal of fortune when technological innovations, especially the discovery of fibre-optics and wireless technology in communication industry, led to declining demand for mineral products. For instance, while in 1980 Africa exported 1.3 million metric tons of copper, by 1993 copper exports fell to just 0.598 million metric tons. Similarly, iron exports fell from 28 million tons in 1980 to 18.9 million in 1993 (World Bank, 2000). As these exports decline so do growth rates.

The fraction of primary commodities in exports is equally important in explaining Africa's slow growth. As expected, it has a negative effect on growth. For the most part, African economies remain undiversified, relying for their foreign exchange earnings on a few primary commodities, usually the ones which have been the mainstay of the economy since colonial days. Although agriculture accounts for between 30 and 40 percent of GDP, agricultural commodities comprise over 80 percent of the export bundle for most countries (World Bank, 2000). In addition, although manufacturing output in Africa accounts for 11 percent of GDP, Africa's share of manufacturing output in the world has averaged a dismal 0.58 percent(UNCTAD, 2002).

Perhaps the most interesting result, is that while the investment share of GDP and the number of years the economy has been open do not have high individual posterior probability, they are significant in combination with other regressors. Since the role of investment fostering economic growth is well documented in the literature, we analyze why the number of years the economy has been open is important in exaplaing Africa's slow growth. Notice that upon independence in the 60s, most of Africa's nationalist governments closed themselves to international trade and instead engaged in import substitution industrialization (Ake, 1985). Those countries which implemented export promotion strategies like Botswana grew rapidly (AJR) while inward-looking economies like Tanzania and Ethiopia stagnated.

Now we turn to the second question: why do some regressors that have high posterior probability in the global sample lose their explanatory power in the Africa-only sample? Two variables fall into this category: the fraction of people that confesses to be Confucian and life expectancy at birth in 1960. The fraction of the population that is Confucian does not affect African growth because no one on the continent professes this religion, hence it was excluded in estimation of the posterior probability in Africa-only sample and in the regressions. In fact, none of the religious variables has any significant posterior probability.

Similarly, life expectancy in 1960 has a low posterior probability in African growth regressions. We conjecture that the combination of limited access to public education, poor public health institutions, low incomes and tropical climatological factors resulted in high morbidity and mortality in general, and high infant mortality in particular, which translated into low life expectancy at birth. While economic theory would suggest that this low initial stock of human capital would negatively affect economic growth through low labor productivity, it is also likely that due to the predominance of the subsistence sub-economy most of the low labor productivity prevailed in the subsistence economy and may not have been accurately captured in the measured part of the market-based economy.

Finally, notice that in both the global and Africa-only samples, the institutional hypothesis is borne out, subject to some qualification. We find that measures of economic institutions have relatively high single and joint posterior probability while indices of political institutions have low posterior probability. These results accord with and contradict findings by Easterly and Levine (2002; 1999) and AJR. To the extent that some initial conditions and economic institutions have high posterior probability, these findings lend support to the institutional hypothesis. However, this support is tapered by the low posterior probability of political institutions and other variables that the growth literature uses to reflect institutional quality, like ethnolinguistic diversity. The latter result accords with Bates (2001), who notes the lack of correlation between ethnic diversity and activities that are disruptive to the attainment economic growth.

In light of these results, we conclude that, given the differences in posterior probability of regressors and potential regression models in the Africa-only and global samples, the determinants of growth in Africa are different from those in the rest of the world. Except for GDP60, globally important regressors have no significant posterior probability in Africa. Neither do they have significant impact in growth regressions. In other words, some regressors which predominate global cross-country regressions mask regional growth patterns.

3.5.3 Robustness

As noted earlier, cross-country regressions are plagued by robustness issues, not the least being model uncertainty. While the proliferation of possible explanatory variables in cross-country regressions provides a wealth of information, due to the relative lack of guidance from economic theory regarding which variables to include in growth models, growth regressions suffer from model uncertainty. Model uncertainty is especially pronounced when particular parameter estimates are only statistically significant in the presence of other particular independent variables (Temple, 1998; FLS). We therefore tested the robustness of our results to inclusion of variables which have been found to be significant in other regressions.

Appendix C, Table C3 reports results of the robustness exercise. In general, our finding is that the posterior probabilities associated with the regressors are robust to inclusion and exclusion of other regressors including alternative measures of institutional quality, the degree of openness and economic organization. Initial output, the share of mining in GDP, the share of primary exports and primary school enrollment remain the most important variables in explaining African growth. However, in the smaller sample when we include a measure for a country's participation in World Bank/IMF sponsored Structural Adjustment Programs (SAPs), the marginal posterior probabilities associated with the primary export variable declined from 92.1 percent to 77 percent while for primary school enrollment in 1960 the probability declined from 73.1 percent to 60.6 percent. In addition, inclusion of the structural adjustment measure raised the posterior probability of the number of years the economy has been open. As a result we investigated in detail the pathways through which structural adjustment may affect African growth.

3.6 Structural Adjustment and African Growth

The paradoxical finding from the preceding section was that regressors that are traditionally considered important for global economic development seemed to have low posterior probability in the Africa-only sample and that the inclusion of a SAPs measure affected the posterior probabilities of some regressors. We conjecture that this results mainly from the use of a cross-section of average data covering over thirty years. Although long time horizons focus our attention on explaining long-term growth patterns, data averaged over long horizons suffer from two potential flaws. First, they overstate the role of initial conditions on long-run growth (Collier and Gunning, 1999). Second they mask any structural transformation that occur within the horizon under consideration. This is especially critical in the African case for two reasons.

Firstly, note that between 1960 and 1973 output per worker, capital per worker, education per worker and total factor productivity were the same in Africa as in East Asia (Collier and Gunning, 1999). However, subsequent to the first oil shock, it became evident that all was not well from the view point of welfare, macroeconomic stability or balance of payments. After 1974, economic growth, growth in total factor productivity and growth in output per worker have been negative on average. As a consequence, African countries have been implementing SAPs since the late 1970s. In varying degrees, countries have carried out macroeconomic and structural reforms with financial and technical assistance from the World Bank and International Monetary Fund aimed at addressing deep-seated structural weakness. Standard structural reforms have included public enterprise restructuring and privatization, retail price decontrols, exchange rate and trade liberalization and other demand management policies aimed at reducing the ratio of the budget deficit to GDP and the rate of inflation.

Second, African growth is strongly episodic. While most growth episodes may be related to political regimes in particular countries, there is no reason to believe that the growth effects of geographical and environmental factors stop at the border. Therefore, there is a high likelihood of geographical externalities and contagion effects of policy, colonial legacy and even civil disturbance. For instance, a civil war or natural disaster in one country floods neighboring countries with refugees who put enormous stress on the receiving nations' resources. Similarly, in many countries reliance on rain-fed agriculture renders short-run economic growth captive to the vagaries of weather conditions, especially drought. We, therefore, need to account for variables underlying such episodes in economic growth which tend to be lost when we use data averaged over long horizons.

In this section, we therefore investigate the determinants of African growth from 1980 when most African countries began implementing SAPs in earnest. We measure exchange rate liberalization using a measure of the real exchange rate distortion (misalignment), trade liberalization with the trade share (the ratio of international trade to GDP). The standard deviation in the consumer price index will proxy the efficiency of demand management policies.[8] In addition, following Calamitsis et al. (1999) we use a measure of SAP implementation compliance, reflecting the frac-

[8]If demand management is focused on reducing fluctuations in output around the full employment level, then the output gap would be a more appropriate measure. However, since estimates of full employment output based on five-year interval data would be more suspect, we chose to use variations in prices.

tion of years in the 1980-1995 period that a country was adjudged as a sustained adjuster by the World Bank and IMF.[9]

To account for growth episodes we introduce a measure of the incidence of drought (World Bank, 2000). A binary classification of "D" was assigned to a country if a significant shortage of rain unfavorably affected its agricultural production. Notice that thus defined, mere below-average rainfall does not necessarily qualify as a drought, if that shortage did not affect a country's food production. We therefore measure incidence of drought by the number of years in the 1980-1995 period that a country was classified by the Food and Agriculture Organization and the World Bank as affected by drought.

Lastly, while it has long been assumed (and occassionally asserted) by those of the institutional school that economic growth may be retarded by the persistence of extractive institutions in post-colonial Africa, many in the dependency school have long argued that African economic development is captive to neo-colonial policies of the developed world, mostly transmitted through investments by multinational corporations, international development organizations and aid agencies (Ake, 1985). Therefore, two measures of economic dependence are included: flows of foreign direct investment and total overseas development assistance from bilateral and multilateral sources. In addition, we also include the debt burden and the growth rate of terms of trade as measures of external macroeconomic stress. Finally, due to the collinear nature of our previous measures of human rights (political right and civil liberties) we introduce a new measure, called freedom, measured as a country's average score on political and civil rights and normalized on a 0-1 scale following FLS.[10]

[9]Credit agreements with the World Bank are inaccurate indicators of participation in SAPs because most countries do not fully comply with World Bank or IMF conditionalities (World Bank, 1994).

[10]In the growth literature institutional indexes abound. Easterly and Levine average six measures of institutional development, voice and accountability, political stability and absence of violence, government effectiveness, regulatory burden, the rule of law and freedom from graft. In contrast, Sachs and Warner (1997) use an average of five sub-indexes published by the political risk services:- the rule of law index, bureaucratic quality, corruption in government, risk of expropriation and government repudiation of contracts.

Table 3.5: Model posterior probability under Structural Adjustment

Model	Regressors	Post. Prob (%)
1	GDP75, Population Growth, Rights, Drought, Lifexp	13.03
2	GDP75, Population Growth, Rights, Lifexp	10.24
3	GDP75, Population Growth, Rights, Lifexp, Landlock	3.44
4	GDP75, Population Growth, Rights	2.45
5	GDP75, Population Growth, Rights, Drought	2.33

3.6.1 Model Posterior Probabilities

Table 3 presents results of model posterior probabilities. The results reported are based on a run with half a million recorded drawings after a burn-in of 100,000 discarded drawings. The model performance is quite satisfactory with a high correlation coefficient between visit frequencies and posterior probability of 0.975. Our model comprises 21 variables and the prior probability of each model is 0.0001 percent. In this sample the posterior mass is concentrated so that the cumulative posterior probability of best 122 models, those with posterior probabilities greater than 0.10 percent, is 82 percent of total posterior mass.

Just like in the 1960-92 sample in the adjustment period, models range between three and seven regressors. The best model in the adjustment context has a posterior probability of 13.87 percent and comprises initial income, population growth, freedoms, drought and initial life expectancy. In addition to these variables, the union of the ten best models shows that African growth is also a function of number of years the economy has been open, the real exchange rate distortion, and lack of access to the sea. Unlike in the 1960-92 sample, in the adjustment period, the share of mining in GDP does not enter the ten best models.

3.6.2 Regressor Posterior Probability

Table 4 reports posterior results for individual regressors from the cross-country growth regression since African nation began implementing SAPs from a basic sample of 21 variables and a larger sample of 31 variables. When we consider the adjustment period, the results suggest that the determinants of growth in Africa differ markedly from those implied by the thirty-two year averages. First, note that except for the level of initial output, other variables which had high posterior probabilities in the 30 year sample, like the fraction of mining output in GDP and the share of primary commodities in exports, lose their posterior explanatory power under structural adjustment. In contrast, in the 1980s and early 1990s, African growth can be explained mostly by population growth rate, the quality of institutions, as measured by the degree of freedom, and the initial stock of human capital (life expectancy in the 1975-1979 period).

There are good reasons why the initial stock of human capital and population growth have higher posterior probability in the 1980s than they did over the 1960-1992 period. During the commodity boom of the 1960s and early 1970s, African countries made significant progress in child immunization, leading to a fall in child morbidity and mortality and a rise in life expectancy at birth. However, since there was no corresponding reduction in fertility and birth rates, this resulted in rapid population growth. For instance, while crude birth rates fell from 45.1 in 1982 to 38.1 in 1997, due to improvements in general public health, mortality rates fell further from 16.0 in 1982 to 13.4 in 1997 which has translated into a population growth rate of 2.7 percent between 1982 and 1997 (World Bank, 2000) and outstriped GDP growth rate.

Second, the evidence suggests that structural adjustment programs, howsoever proxied, have low posterior probability in explaining African growth. Neither the degree of country compliance with the World Bank-IMF conditionalities, the move towards a more open trade regime nor the elimination of exchange rate distortion

Table 3.6: Posterior probabilities of regressors under Structural Adjustment

	Regressor	Basic Sample	Full Sample
1	Population Growth	0.9957	0.9805
2	Initial Output	0.9925	0.9754
3	Freedom	0.9354	0.8981
4	Life Expectancy, 1975	0.8494	0.8173
5	Drought	0.5073	0.4532
6	Years Economy open	0.1635	0.1306
7	Landlocked	0.1104	0.1062
8	Exchange Rate Distortion	0.0722	0.0779
9	Inflation	0.0665	0.0471
10	British Colony Dummy	0.0470	0.0476
11	Fraction of Mining in GDP	0.0476	0.0363
12	Investment	0.0388	0.0286
13	Foreign Direct Investment	0.0384	0.0262
14	Structural Adjustment	0.0351	0.0243
15	Primary Exports, 1970	0.0348	0.0235
16	Trade Share	0.0343	0.0241
17	French Colony Dummy	0.0300	0.0209
18	ODA	0.0302	0.0175
19	Area(Scale Effect)	0.0282	0.0178
20	Economically Active Population	0.0274	0.0155
21	Growth Terms of Trade	0.0270	0.0136
22	Economic Organization		0.1234
23	English Speaking Fraction		0.0910
24	Debt-Export Ratio		0.0683
25	Fraction Protestant		0.0398
26	Muslim		0.0249
27	Openess		0.0196
28	Revolutions and coups		0.0174
29	Fraction Catholic		0.0170
30	War Dummy		0.0146
31	Ethnolinguistic Fractionalization		0.0139

appear to have any significant posterior probability. This is inconsistent with both sides in the adjustment debate. While some have argued that adjustment programs have negative impacts on growth both in the short run (Conway, 1994) and long run (Przeworski and Vreeland, 2000), others maintain that any apparent ineffectiveness of SAPs should be blamed on lack of commitment by adjusting nations (Killick,1997).

Third, economic dependence does not seem to undermine economic growth in Africa. All measures of international economic dependence, the debt-export ratio, foreign direct investment and overseas development assistance have low posterior probabilities. Owing to a lack of protection of property rights and enforcement of contracts, African economies are generally viewed as capital-hostile so that only sure and high yielding investments are undertaken. In addition, low posterior probability associated with Overseas Development Assistance seems to reflect problems associated with asymmetric information, especially moral hazard and fungibility of aid. In most countries, there is little guarantee that aid money will be used for purposes for which it was given.[11]

These results are robust to inclusion of other variables. We rerun the model with 31 variables. The third column of table 3 shows that the posterior probabilities and relative ranking of most regressors remain unchanged when we reintroduce traditional measures of institutional quality (like war, revolution and coups and colonial influence), religious variables and the nature of economic organization. Their inclusion and exclusion shows that these variables have low posterior explanatory power on African growth either between 1960 and 1995 or 1980 and 1995.

There two general conclusion from this section. First, looked at in a medium-to-long-term perspective, determinants of African growth still differ markedly from variables that are globally important. Second, when we account for structural transformation during the adjustment period and the episodic nature of African growth,

[11] For instance, the World Bank found that in the 1980s as much as 40 percent of Malawi's annual development budget was diverted to the construction and maintenance of presidential residencies (World Bank, 1995).

we find that determinants of African growth in the medium term are different from those in the long term.. We find that some geographical, policy and institutional variables have high posterior probability.

3.7 Conclusion

In this paper we investigate determinants of economic growth in Africa. In so doing we also investigated whether these determinants are sufficiently different from those explaining global economic development as to warrant a separate theory of African economic growth. Our results reject the assertion that African growth can be explained in terms of factors that are important for global economic growth but are lacking in Africa. We found that variables that are important in the global sample lose their explanatory power in the Africa only-sample. In addition, results of posterior model probabilities suggest that the combination of variables relevant for explaining African growth differs from combinations that are important for global economic growth.

These implications are further born out in the medium term. In the adjustment period we also rejected the null hypothesis that determinants of growth in Africa were the same as those elsewhere (Sachs and Warner, 1997). However, in the medium term while there was some evidence for political institutional factors (Freedom) and geographical factors (drought and being landlocked), the majority of regressors with high posterior probability were those related to initial conditions and economic institutions. In varying degrees our findings concur with and contradict recent contributions by AJR and Easterly and Levine (1999), on the one hand and Sachs and Warner (1997), on the other hand. The former argue that Africa's slow growth can be explained in terms of the institutional variables, while the latter authors maintain that good policies and institutions can significantly improve Africa's economic performance if we control for the effect of geography.

There are some areas worthy of future research that this article mentioned in passing. First, it is acknowledged that African growth in the 1990s has been adversely affected by AIDS, which reduced the quantity and quality of human capital. In addition, while this article acknowledged that African growth is episodic, developing a methodology for systematic identification of these episodes presents a promising line of future research into the inquiry of African growth. If these growth episodes were separately identified, then nonlinearities and hysteresis underlying African growth might be found (Collier and Gunning, 1999).

Chapter 4

Initial Conditions as Threshold Variables in Economic Development

4.1 Introduction

Standard one-sector models of growth have the counterfactual implication that nations with identical economic structures would converge to the same steady state or balanced growth path. The implication is that absent differences in initial conditions, nations which share common fundamentals and are structurally identical will converge to the same steady state. A further implication is that poor nations, which are lacking in growth enhancing resources, should grow faster and eventually catch up with developed economies as production techniques diffuse from the developed to developing nations. However, international evidence on growth rates in per capita incomes belies these postulations and reveals persistent differences in development patterns among nations and shows unequivocally that, rather than converging, the world distribution of per capita income is multi-modal with several basins of attraction (Azariadis, 1996).[1] While some countries manage to sustain high growth rates over long periods of time, others seem to stagnate in poverty traps, characterized by persistently low rates of growth or low level of economic development or both

[1]Much of the development literature refers to the lowest of these basins of attraction "poverty traps" or "low-development trap".

(Azariadis and Drazen, 1990). However, even more troubling is the realization that even structurally identical economies grow differently.

The economics literature has proffered three sets of possible proximate causes of these persistent differences in economic growth among countries: the *fundamental approach* is premised on the notion that structurally identical countries may follow distinct development paths because they are inherently different in one or more fundamental aggregate features (for example time preferences or economic policy).[2] The *multiple equilibrium view* focuses on the role of beliefs in sustaining economic growth (Benhabib and Gali, 1995). It posits that beliefs and community expectations can influence phenomena like overtaking and rank reversal so that some nations in the world income distribution gain at the expense other, apparently similar, nations. However, the third view, the *historical view* argues that "cross-country growth would be fundamentally same except for differences in history, i.e. in the circumstances from which the growth process begins" Azariadis (1996: p.452). This literature has especially focused on the role of initial stocks of human capital and physical capital and the state of technology in affecting economic growth.

This paper seeks to investigate the *historical view*. The main question is, to what extent do initial conditions and nature preserve and augment initial inequality in per capita incomes among otherwise identical national economies? This is important because the issue of whether per capita income levels in countries are converging hinges on the role of initial conditions on long-run development. If initial conditions are irrelevant in the long-run, then income levels will converge globally after controlling for any pertinent microeconomic heterogeneity (Johnson and Takeyama, 2001). However, if initial conditions are important, then they can create history-dependent growth paths which in turn will result in history-dependent development.

[2]This view underlies most Solow-type models, e.g. models by Mankiw Romer and Weil (1992) and Barro and Sala-i-Martin (1995).

There arises the need, therefore, to ascertain whether existing differences in growth rates across nations reflect temporary deviations from a common stochastic steady state or the permanent effects of differences in initial conditions. The specific question now becomes: are poor countries merely victims of the circumstances in which they are initially placed by chance, environment or history? If so, can initial conditions reflecting chance, history or environment, shed any light on how countries find themselves in international convergence clubs, where membership is defined by reference to the threshold level of these initial condition? Durlauf and Johnson (1995) find support for the role of initial level of economic development (measured by initial output) and initial stocks of human capital (measured by adult literacy rates) in a cross section of 96 countries while Johnson and Takeyama (2001) find threshold effects for the density of initial capital stock among the 48 contiguous US states. This essay extends Durlauf and Johnsons' (1995) analysis using alternative measures of initial conditions and human capital. In this paper we address role of initial conditions using the endogenous threshold technique developed by Hansen (2000).

The rest of the paper is organized as follows. Section 4.2 briefly discusses the theory and empirics of threshold estimation while Section 4.3 describes the data and presents diagnostic tests. Section 4.4 employs the Hansen (2000) endogenous threshold methodology to examine the possibility of threshold effects. Section 4.5 discusses the implication of the findings and concludes.

4.2 Endogenous Threshold Estimation

The standard approach to empirical cross-country growth analysis uses a common, coefficient-invariant linear regression model of the form

$$g_i = \beta_x' X_i + \beta_z' Z_i + u_i \tag{4.1}$$

where g_i is real per capita income growth in economy i over a given time period and X_i is a vector of the variables suggested by the Solow growth model. According to the Solow model, this vector of explanatory variables comprises the log of initial per capita real income at the beginning of the period over which growth is measured, the log of the savings rate for physical capital accumulation out of output, the log of the savings rate of human capital[3], and the log of $(n_i + \rho + \delta)$, where n_i is growth rate of the working population in country i, ρ represents the common rate of technical change and δ represents the depreciation rates of physical and human capital stocks. Z_i is a vector of additional country-specific covariates that augment the basic Solow model. As such Z_i allows the researcher to include any additional variables or measures of development that the researcher deems pertinent to explaining economic growth.

In this essay this vector will contain any initial conditions whose growth effects are being investigated. Let $q_{it} \in Z_{it}$ be a scalar threshold variable and γ denote the threshold. Then in the threshold estimation context, countries will be divided into "regimes" depending on whether the threshold variable (q_{it}) is larger or smaller than the threshold (γ). The notion of threshold effect in a growth regression specifies that countries can be divided into classes based on the value of some observed variable (in this case some initial condition). This implies that equation (4.1) can simply be written as

$$g_i = \begin{cases} \beta_1' X_i + u_i, & q_{it} \leq \gamma \\ \beta_2' X_i + u_i, & q_{it} > \gamma \end{cases}$$

Unfortunately, while the theory of thresholds has made significant strides toward general acceptance, general application of threshold models is stymied by a dearth of robust empirical techniques. For the most part, threshold estimation has been based on regression tree methodology (e.g. Durlauf and Johnson, 1995; and Johnson and Takeyama, 2001). However, this essay searches for, tests and estimates thresholds using a relatively new approach, the "endogenous threshold methodology"

[3]Human capital enters the model based on Mankiw, Romer and Weil's (1992) augmentation of the the basic Solow equation.

of Hansen (2000). The main advantage of Hansen's methodology over the regression-tree methodology is that the former is based on an asymptotic distribution theory which allows for formal tests of the statistical significance of thresholds and regimes selected by the data.[4]

We implement this framework using the standard cross-country growth regression equation, employed in much of the empirical growth literature:

$$g_i = \alpha_0 + \alpha_1 \ln(\frac{Y}{L})_{i,60} + \alpha_2 \ln s_{ki} + \alpha_3 \ln s_{hi} + \alpha_4 \ln(n + \rho + \delta) \tag{4.2}$$

where g_i is the growth rate of real per capita GDP for the population aged 15-64 in country i between 1960 and 1985, s_{ki} is the fraction of real GDP devoted to investment including government investment, averaged over 1960-1985, s_{hi} is the fraction of the working age population enrolled in school, averaged over 1960-1985. n_i, ρ and δ are as defined above. Following standard practice we assume that $\rho + \delta = 0.05$ (see Mankiw Romer and Weil, 1992).

4.3 Data and Diagnostics

The baseline dataset employed in our estimation is identical to that used in Durlauf and Johnson (1995). The variables used in the baseline estimation are: per capita output in 1985, the average investment to GDP ratio between 1960 and 1985 (s_{ki}), the average percentage of working age population (population between the age of 15 and 64) in secondary education over the period 1960-1985 (s_{hi}), and the average of the working age population growth rate from 1960-1985. These data are from Summers and Heston (1988), Real National Accounts.

Following Durlauf and Johnson (1995) and Hansen (2000), we first search for thresholds in the data using initial per capita output ($(Y/L)_{60}$) and initial adult

[4]For a detailed discussion of the statistical theory for threshold estimation in linear regressions, see Hansen (2000).

Table 4.1: Description of threshold variables and diagnostic test results

Mnemonic	Description	P-value
$(Y/L)_{60}$	Real per capita output, working age population in 1960 from Summers and Heston (1988)	0.078
LIT60	Adult literacy rate, fraction aged 15 and over that is able to read and write in country *i* in1960	0.030
LIFE60	Life expectancy at birth in 1960	0.002
P60	Gross primary enrollment rate in 1960	0.001
S60	Gross secondary school enrollment rate in 1960	0.129
H60	Gross enrollment rate in higher education in 1960	0.009
AREA	Land area in millions of square kilometers	0.214
LAT	Absolute latitude, distance from the equator	0.194
ETHNO	Ethnolinguistic diversity, probability that two randomly selected people from one country will not belong to the same ethnic or linguistic group	0.122
PRIEXP70	Share of primary commodities in exports, 1970	0.038
URB60	Fraction of the population which lived in urban areas in 1960	0.012

literacy rates (LIT_{60}) as possible threshold variables.[5] Adult literacy rates are measured as the fraction of population over the age of 15 that was able to read and write in 1960 and data are from the World Bank's *World Report.*

Thereafter, we test for threshold effects using other initial conditions which can potentially affect long-run growth in per capita income. Table 4.1 describes the variables which will be used as threshold variables and their associated P-values in the first round of threshold estimation. Notice that some of these initial conditions capture the initial level of economic development (e.g. $(Y/L)_{60}$, $PRIEXP_{70}$ and URB_{60}), while others represent initial stocks of human capital (LIT_{60}, $LIFE_{60}$, P_{60}, H_{60} and S_{60}) and the remaining variables reflect natural conditions (LAT, AREA and ETHNO). The entire sample used here includes 90 rather than 96 countries used in Durlauf and Johnson (1995) and Hansen (2000) and Papageorgiou (2002). Angola,

[5]In order to compare our model predictions with those of Durlauf and Johnson (1995) and Hansen (2000) we first consider the two threshold variables considered in these papers. Both papers found that inital output and initial literacy had a significant threshold effect.

Bangladeshi, Bolivia, Burkina Faso, Burma and Indonesia were eliminated since there are no data on the additional initial conditions for these countries.

Table 4.1 also reports bootstrap P-values from diagnostic tests of the threshold effects for all the variables. Notice that most of the initial level of economic development and human capital variables have significant threshold effects at conventional levels (P-value < 0.10) while natural conditions like location, ethnic and linguistic composition of the population and size of the country have no threshold effects. For the variables with significant P-values, we proceed to estimate the thresholds and derive the implied regimes.

4.4 Empirical Estimation and Results

For expositional purposes we will consider the three sets of initial conditions and derive generalizable implications. We first establish that our results are consistent with the baseline results of Durlauf and Johnson (1995) and Hansen (2000) who only employed initial output and initial literacy rates. Then we extend these studies by testing for threshold effects using alternative measures of the initial stocks of human capital and the initial level of economic development.

4.4.1 Initial Output as Threshold Variable

In the first round of splitting, we find that the model using initial output as a threshold is significant with P-value at 0.078 signifying that there may be a sample split based on initial output. Figure 4.1 presents the normalized likelihood ratio sequence $LR_n^*(\gamma)$ statistic as a function of the output threshold. The least-squares estimate of the threshold (γ) is the value that minimizes the function $LR_n^*(\gamma)$ and occurs at $\hat{\gamma} = \$863$. The asymptotic 95% critical value (7.35) is shown by the dotted line and where it crosses $LR_n^*(\gamma)$ displays the confidence set $[\$594, 1430]$.

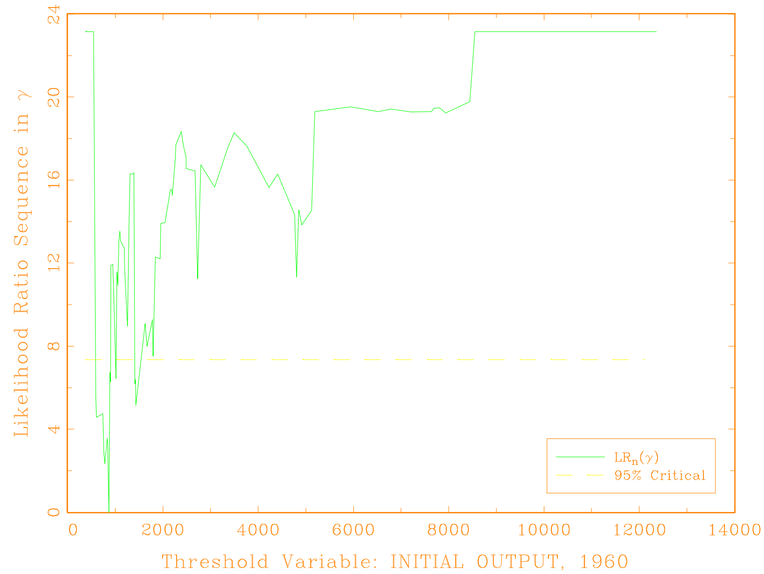

Figure 4.1: First sample split using initial output

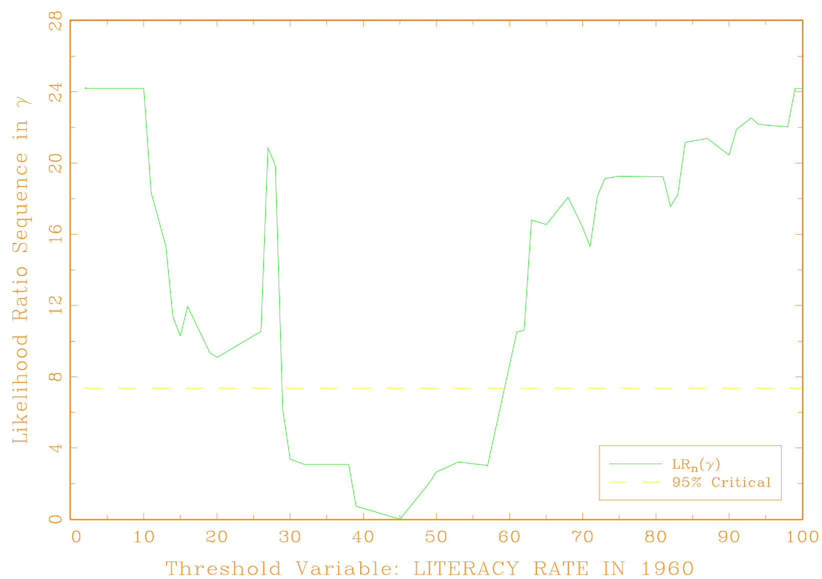

Figure 4.2: Second sample split using literacy rate

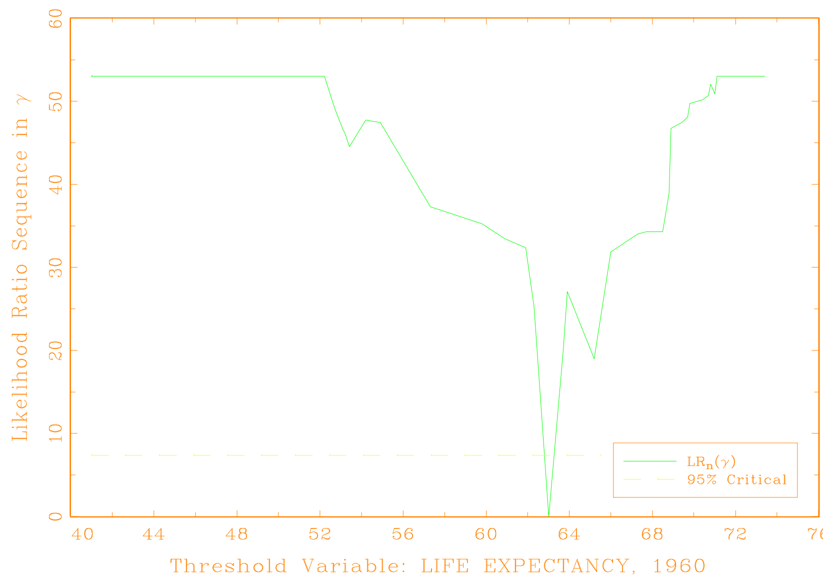

Figure 4.3: Third sample split using life expectancy

The first output threshold divides our sample of 90 countries into a low-income group with 15 countries and a high-income group with 75 countries. It is interesting to note that although our sample is smaller than that used by Hansen (2000), the sample size did not significantly affect the qualitative implications of using initial output as a threshold variable. In both samples we find the same threshold. However, due to loss of observations, our confidence set is smaller than theirs [$574, 1794], and their low income group had 18 countries while the higher income group had 78 countries.

Since further splitting of the low-income group was not possible, our second round of threshold model selection involved all variables and the 75 countries with per capita incomes above $863. Five of the variables obtained significant P-values for threshold: 0.068 for initial output, 0.022 for literacy, 0.032 for life expectancy, 0.95 for primary school and 0.045 for the share of primary commodities in exports. Since initial literacy had the most significance, we report the second round threshold based on the split given by the literacy rate. Figure 4.2 presents the normalized likelihood

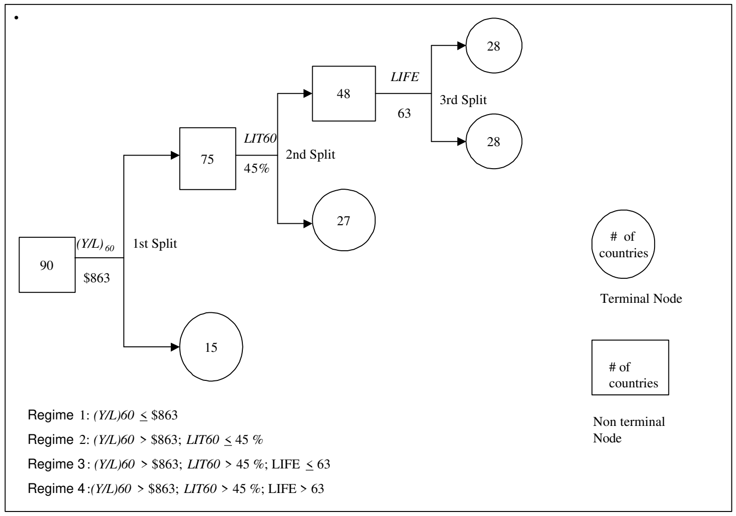

Figure 4.4: Threshold and regimes using initial output

ratio statistic as a function of the literacy rate threshold. The point estimate for the literacy threshold is $\hat{\gamma} = 45\%$ with the 95% confidence set equal to $[29\%, 57\%]$. The literacy rate threshold variable splits the high-income sub-sample of 75 countries into two additional groups; a low-literacy group with 27 countries and the high-literacy group with 48 countries. Again notice that these results are identical to the baseline results of Hansen (2000). The literacy threshold is the same. However, since they have three more observations, their low literacy group has 30 countries, while the high literacy group has the same 48 countries.

Our third and final round of threshold model selection involves the 48 countries with initial per capita output above \$863 and initial literacy rates above 45%. In the baseline study, Hansen (2000) both initial output and literacy rates had no third level threshold effects. However, in our study we find that life expectancy at birth exhibits threshold effects with P-value at 0.006. The thrshold estimate for life expectancy occurs at 63 years. The normalized likelihood ratio statistic as a function of the life expectancy threshold is illustrated in Figure 4.3. Life expectancy at birth splits the high-literacy group into a high-literacy, low-life expectancy group of 20 countries and a high-literacy, high-life expectancy group of 28 countries. We have tried to further split these sub-samples, but none of the bootstrap test statistics were significant enough.

Figure 4.4 uses a tree diagram to illustrate our thresholds, the regimes described in the preceding discussion and results. Non-terminal nodes are given by squares whereas terminal nodes are represented by circles. The numbers inside the squares and circles represent the number of countries in each node. The point estimates for each threshold variable are presented on the rays connecting the nodes. It is clear from Figure 4.4 that although our sample is smaller than the baseline, this does not affect the thresholds of the remaining observations implied by the baseline. Given our additional threshold variables, further spliting of the high literacy group results in four endogenously determined regimes rather than three found by Hansen (2000). Moreover, the composition of these regimes are different across models.

Table 4.2 presents the countries in each regime obtained from our threshold estimation. The first regime, which is characterized by low per capita income comprises 15 countries, 14 of which are African and ten of them have had civil strife during the past 40 years. These countries are poor even by African standards. Regime 2 has relatively middle-income countries who have low literacy. It comprises mainly of African and middle Eastern countries. Regime 3 represents middle-income highly-literate countries. With some good fortune they can join the ranks of the developed nations. Regime 4 is comprised mainly of mature western democracies who have high income, high literacy and their citizens enjoy reasonably high life expectancies.

We also used alternative sample splitting for the second round of threshold estimation, whereby we replaced literacy rate with the gross primary school enrollment rate. Figures D1 and D2 and Table D3 in the appendix depict the likelihood ratio sequences, the tree diagram and the country classification table, respectively,

Table 4.2: Country classification using initial output threshold

Regime 1	Regime 2	Regime 3	Regime 4
Burundi	Algeria	Brazil	Argentina
Central Afr. Rep.	Benin	Chile	Australia
Ethiopia	Cameroon	Colombia	Austria
Liberia	Chad	Costa Rica	Belgium
Malawi	Congo	Dominican Rep.	Canada
Mali	Cote d'Ivoire	Ecuador	Denmark
Mauritania	Egypt	El Slavado	Finland
Nepal	Ghana	Jamaica	France
Niger	Guatamala	Madagascar	Greece
Rwanda	Haiti	Malaysia	Hong Kong
Sierra Leone	Honduras	Mexico	Ireland
Tanzania	India	Nicaragua	Israel
Togo	Jordan	Panama	Italy
Uganda	Kenya	Peru	Japan
Zaire	Morocco	Phillipines	New Zealand
	Mozambique	S. Korea	Netherlands
	Nigeria	S. Africa	Norway
	Pakistan	Sri Lanka	Paraguay
	Papua N.Guinea	Thailand	Portugal
	Senegal	Venezuela	Singapore
	Somalia		Spain
	Sudan		Sweden
	Syria		Switzerland
	Tunisia		Tri. & Tobago
	Turkey		United Kingdom.
	Zambia		United States.
	Zimbabwe		Uruguay
			West Germany
(15)	(27)	(20)	(28)

for this alternative model where the primary enrollment rate was the second-round threshold variable and latitude was the third round variable. Notice that just like in the current estimation, the alternative threshold estimation divides the high income group into three groups: a group with high-income, low-primary enrollment (10 countries), a high-income high primary enrollment group of 30 tropical countries and a group of 35 temperate countries with high income and high primary enrollment rates.

4.4.2 Literacy as Threshold Variable

As shown in table 4.1, the diagnostic test for initial literacy as the threshold variable returned a significant P-value of 0.0160 signifying that there may be a sample split based on initial literacy. The P-value also indicates that the threshold effects of literacy may be more pronounced than those of initial output (P-value for output was relatively less significant).[6] Figure 4.5 presents the normalized likelihood ratio sequence $LR_n^*(\gamma)$ statistic as a function of the literacy threshold. The least-squares threshold estimate (γ) occurs at $\hat{\gamma} = 29\%$. However, the wide asymptotic confidence set of $[9\%, 61\%]$ indicates that there are significant disparities in literacy across nations. The literacy threshold splits the sample into a low-literacy group with 34 countries and a relatively high-literacy group of 56 countries.

Compared to the previous model (using initial output), when we consider the entire sample, literacy rates imply a cut-off point of 29 %. However when literacy is used as a second-level threshold variable among countries with incomes higher than $863, then the relevant cut-off rises to 45 %.

Further tests indicate existence of thresholds in both the low and high literacy sub-samples. For the low literacy group (with literacy rate below 29%), the variable with the most significant threshold effects was the share of primary commodities in exports (P-value = 0.034). The point estimate for the threshold is $\hat{\gamma} = 0.95$

[6]However, literacy is more sensitive to sample size. With a larger sample, the basekine study of Hansen (2000) found initial literacy to be insignificant as a first level threshold variable ($P-$value = 0.168).

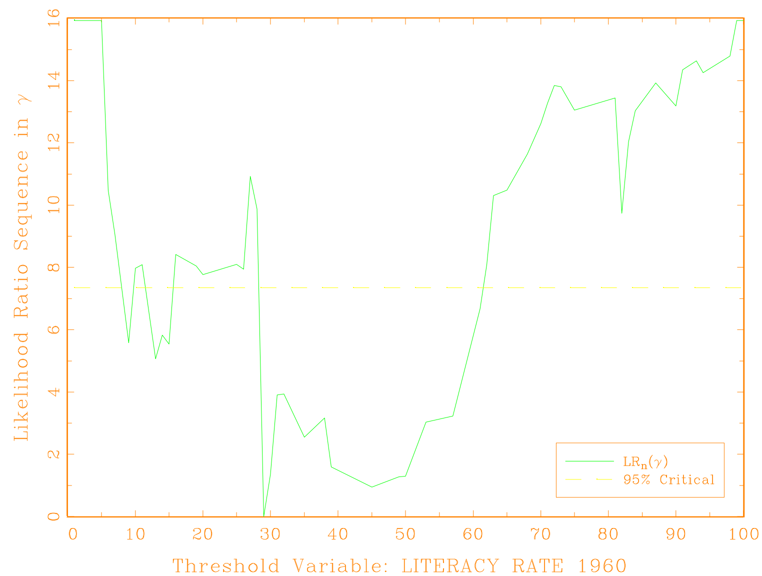

Figure 4.5: First sample split using initial literacy

and divides the low literacy group into a primary commodity dependent group of 12 countries and another group of low literacy but relatively less dependent on primary commodities group of 22 countries.

In the second round of threshold model selection of the 56 high literacy countries, only latitude obtained significant test results for a threshold (P-value = 0.027) with an implied point estimate for the threshold of $\hat{\gamma} = 19.56$. Absolute latitude as a threshold variable splits the high-literacy sub-sample of 56 countries into two additional groups: a high-literacy tropical group of 24 countries and the high-literacy temperate group of 32 countries.[7]

Our third and final round of threshold model selection involves the 32 high-literacy temperate countries. Notice that membership of this groups can be further disaggregated on the basis of reliance on primary commodities. Using the share of primary commodities in exports, the point estimate for the threshold is $\hat{\gamma} = 0.65$, and this splits the sub-sample into a high-literacy, temperate but commodity-dependent

[7]It is also worth noting that most of the 34 countries classified as low-literacy lie within the tropics of cancer and Capricorn.

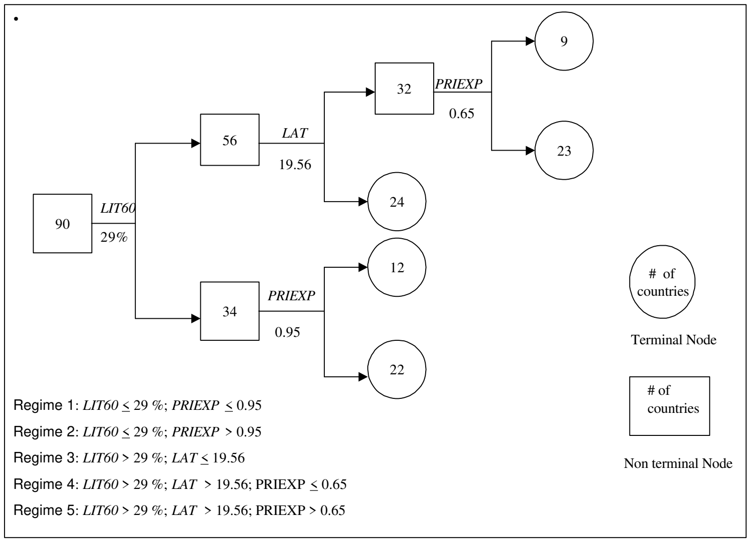

Figure 4.6: Threshold and regimes with literacy as threshold variable

group of 9 countries and a high-literacy, temperate but mature economic group of 23 countries. This results in five regimes which are illustrated in Figure 4.6. In addition Table 4.3 lists the countries in each regime. Notice that countries in Regime 1 and regime 2 are essentially those of regimes 1 and 2 under the output threshold.

Besides the share of primary commodities in exports, ethnolinguistic diversity exhibited a significant P-value for the 34 low literacy countries, in the second round. Ethnolinguistic diversity gives a point estimate of the threshold of 0.66 hereby dividing 34 countries into a low-literacy high ethnic diversity group of 19 countries and a low literacy-low ethnic diversity group of 15 countries. Figure D2 in the appendix shows the tree diagram while Table D1 presents the alternative country classification for this exercise.

Table 4.3: Country classification using literacy as threshold variable

Regime 1	Regime 2	Regime 3	Regime 4	Regime 5
Algeria	Burundi	Brazil	Argentina	Austria
Benin	Ethiopia	Colombia	Australia	Belgium
Cameroon	Ghana	Costa Rica	Chile	Canada
C. Afr. Rep	Liberia	Dom. Rep.	Jordan	Denmark
Chad	Malawi	Ecuador	N. Zealand	Hong Kong
Congo	Mauritania	El Slavado	Paraguay	Finland
Cote d'Ivoire	Niger	Guatamala	Syria	France
Egypt	Nigeria	Honduras	Turkey	Greece
Haiti	Papua N. Guinea	Jamaica	Uruguay	Ireland
India	Rwanda	Madagascar		Israel
Kenya	Sudan	Malaysia		Italy
Mali	Zambia	Mexico		Japan
Morocco		Nicaragua		Netherlands
Mozambique		Panama		Norway
Nepal		Peru		Portugal
Pakistan		Phillipines		S. Africa
Senegal		Singapore		S. Korea
Sierra Leone		Sri Lanka		Spain
Somalia		Thailand		Sweden
Tanzania		Tri. & Tobago		Switzerland
Togo		Uganda		U.K.
Tunisia		Venezuela		U.S.A.
		Zaire		W. Germany
		Zimbabwe		
(22)	(12)	(24)	(9)	(23)

4.4.3 Higher Education Enrollment as a Threshold Variable

Probably gross enrollments in higher education provide the most interesting insight into threshold analysis among the initial conditions. The diagnostic test for higher education enrollment as the first level threshold variable returned a significant P-value of 0.047, signifying that there may be a sample split based on enrollment in high education. What makes higher education interesting is the fact that in 1960, most developing countries had virtually no institutions of higher learning. Figure 4.7 presents the normalized likelihood ratio sequence $LR_n^*(\gamma)$ statistic as a function of the higher education enrollment threshold. It is apparent from the picture that enrollment

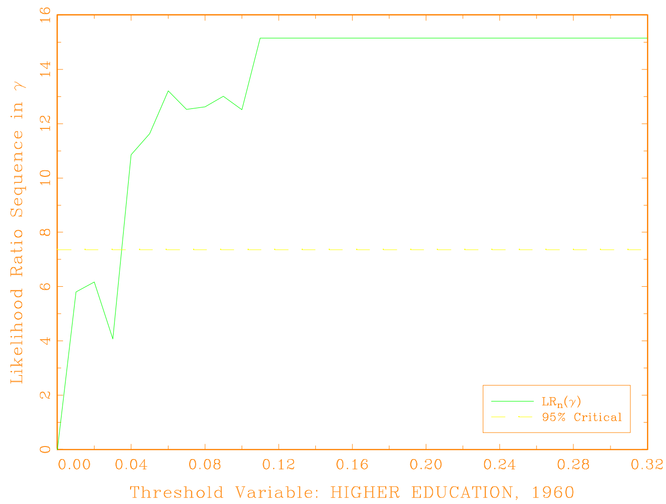

Figure 4.7: First sample split using enrollment in higher education

in institutions of higher learning is an abnormal threshold variable. Although the least-squares threshold estimate occurs at $\hat{\gamma} = 0.00$ with an asymptotic confidence set of $[0, 0.03]$, the threshold variable splits the sample into a group of 32 countries with a zero enrollment in high education and another group of 58 countries with non-zero enrollment in higher education. This is especially interesting because, as earlier indicated, a threshold based on high education signifies a potential for development trap due to lack of professional and administrative capacity.

However, the group of countries with zero gross enrollments are not homogeneous. Further tests indicate possible existence of thresholds in both sub-samples. The low enrollment group (with gross enrollment in high education rate equal to zero), can be distinguished on the basis of initial income which has a conditional P-value of 0.042. The point estimate for the initial output threshold is $\hat{\gamma} = \$863$ and divides the low enrollment group into a low income, low enrollment group of 14 countries and a group of 22 countries with relatively high income but zero gross enrollment in higher education.

In addition, the 58 countries with some enrollment in institutions of higher learning can be divided into three sub-groups. In the second round of threshold model selection of the 58 countries with some high education enrollment, only latitude obtained significant test results for a threshold (P-value $= 0.022$) with an implied point estimate for the threshold of $\hat{\gamma} = 25.27$ and an asymptotic confidence interval of $[18.06, 32.2]$. Absolute latitude as a threshold variable splits the countries with some enrollment in higher education into a sub-sample of 23 tropical countries and another group with predominantly temperate climatic conditions comprising 35 countries.

Finally the 35 countries characterized by high gross enrollment and temperate climates can be distinguished by initial life expectancy, which gives a threshold point estimate of $\gamma = 67.3$ years, this splits the sub-sample into a group with relatively low life expectancy (14 countries) and a high life expectancy group of 21 countries. just like in the case of literacy rates, using gross enrollment in higher education as a first level threshold variable, results in five regimes which are illustrated in Figure 4.8 and listed in Table 4.4.

4.4.4 Primary Enrollment as Threshold Variable

Primary enrollment has the highest marginal significance as a first level threshold variable with a significant P-value of 0.001. The implied least-squares estimate of the threshold occurs at $\hat{\gamma} = 0.61$ and the asymptotic 95% confidence set of $[0.44, 0.61]$ shows considerable concentration around the threshold value. Figure 4.9 presents the normalized likelihood ratio sequence $LR_n^*(\gamma)$ statistic as a function of the primary enrollment threshold. The primary enrollment threshold splits the sample into a low primary enrollment group of group with 33 countries and a high primary enrollment group of 57 countries.

Surprisingly, further tests indicated that it not possible to split the group of 57 countries with high primary school enrollment rates. However, further splitting

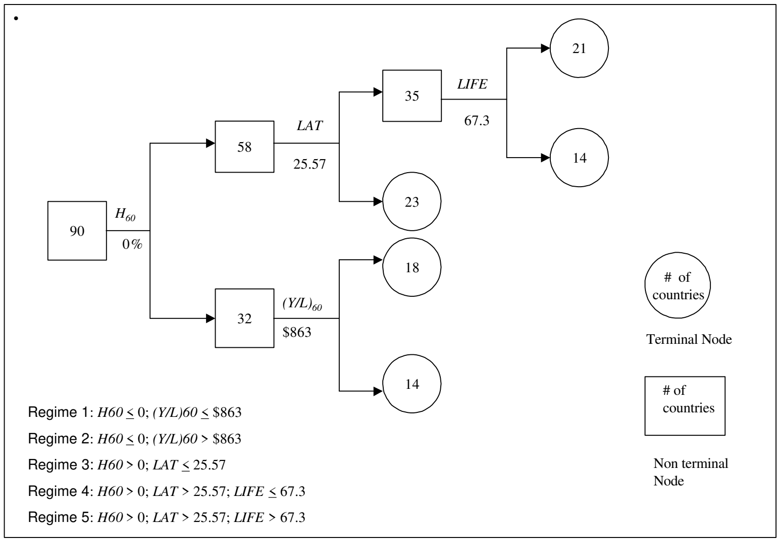

Figure 4.8: Thresholds and regimes using higher education as threshold variable

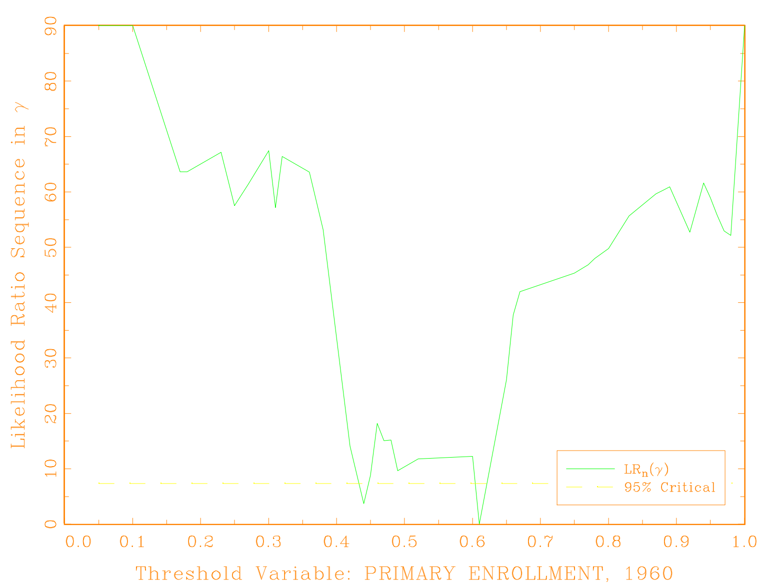

Figure 4.9: First split using primary education as threshold variable

Table 4.4: Country classification using higher education as threshold variable

Regime 1	Regime 2	Regime 3	Regime 4	Regime 5
Burundi	Algeria	Brazil	Argentina	Australia
C. Afr. Rep	Benin	Colombia	Chile	Austria
Ethiopia	Cameroon	Costa Rica	Egypt	Belgium
Liberia	Chad	Dom. Rep.	Jordan	Canada
Malawi	Congo	Ecuador	Nepal	Denmark
Mali	Ghana	El Slavado	Pakistan	Finland
Mauritania	Haiti	Guatamala	Paraguay	France
Niger	Kenya	Honduras	Portugal	Greece
Rwanda	Madagascar	Hong Kong	S. Africa	Ireland
Sierra Leone	Morocco	India	S. Korea	Israel
Tanzania	Mozambique	Jamaica	Syria	Italy
Togo	Nigeria	Malaysia	Tunisia	Japan
Uganda	Papua N. Guinea	Mexico	Turkey	Netherlands
Zaire	Senegal	Nicaragua	Uruguay	New. Zealand
	Somalia	Panama		Norway
	Sudan	Peru		Spain
	Zambia	Phillipines		Sweden
	Zimbabwe	Singapore		Switzerland
		Sri Lanka		U.K.
		Thailand		U.S.A.
		Tri. & Tobago		W. Germany
		Venezuela		
14	18	23	14	21

of the low enrollment group was possible using the rate of urbanization in 1960. The point estimate for the threshold is $\hat{\gamma} = 0.13$ and divides the low literacy group into a primary commodity dependent group of 12 countries and low-literacy group with low dependency on primary commodities (see Table 4.5 and Figure 4.10).

A close examination of Table 4.5 shows why further threshold effects could not be established. Although, regimes 1 and 2 contain the usual suspects, low income sub-Saharan African countries, regime 3 contains four notable outliers: Cameroon, Congo, Malawi and Zimbabwe. While the gross enrollments classify these countries into this group, the disparities between these four and the rest of the group are so wide that a meaningful threshold can not be found. We conjecture that this may

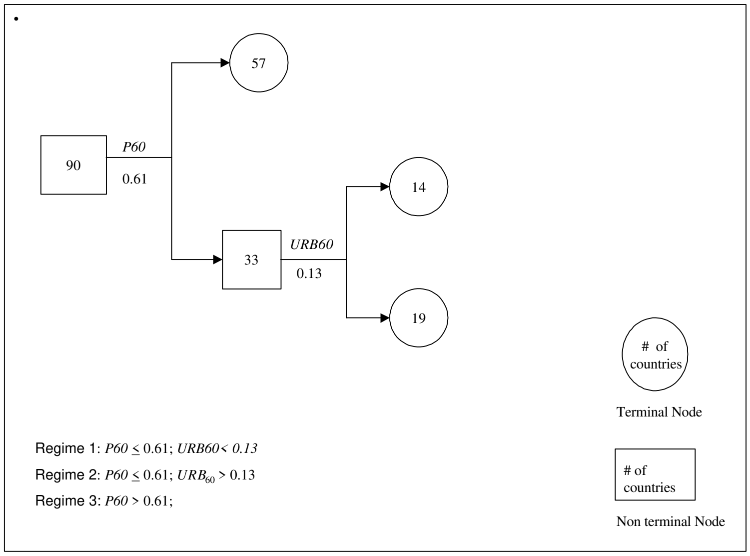

Figure 4.10: Thresholds and regimes using primary education as threshold variable

be due to suspicouis quality of enrollment data from these four countries. Note that these countries had high primary enrollments yet low literacy rates.

4.4.5 Primary Exports as Threshold Variable

The final threshold estimation questions whether economies can be distinguished on the basis of initial composition of output or exports? The diagnostic test for share of primary exports as the first level threshold variable obtains a significant P-value of 0.0038 signifying the existence of threshold effects from the initial share of primary commodities in exports. Figure 4.11 presents the normalized likelihood ratio sequence $LR_n^*(\gamma)$ statistic as a function of the primary exports threshold. The associated least-squares threshold estimate occurs at $\hat{\gamma} = 0.93$ with an asymptotic confidence set of $[0.92, 0.95]$. There are 23 countries where the share of primary commodities in exports in 1970 exceeds the threshold and 67 countries where primary commodities accounted for less than 0.93 of exports.

Table 4.5: Country classification using primary education as threshold variable

Regime 1	Regime 2	Regime 3	Regime 4	Regime 5
Algeria	Burundi	Brazil	Argentina	Austria
Benin	Ethiopia	Colombia	Australia	Belgium
Cameroon	Ghana	Costa Rica	Chile	Canada
C. Afr. Rep	Liberia	Dom. Rep.	Jordan	Denmark
Chad	Malawi	Ecuador	N. Zealand	Hong Kong
Congo	Mauritania	El Slavado	Paraguay	Finland
Cote d'Ivoire	Niger	Guatamala	Syria	France
Egypt	Nigeria	Honduras	Turkey	Greece
Haiti	Papua N. Guinea	Jamaica	Uruguay	Ireland
India	Rwanda	Madagascar		Israel
Kenya	Sudan	Malaysia		Italy
Mali	Zambia	Mexico		Japan
Morocco		Nicaragua		Netherlands
Mozambique		Panama		Norway
Nepal		Peru		Portugal
Pakistan		Phillipines		S. Africa
Senegal		Singapore		S. Korea
Sierra Leone		Sri Lanka		Spain
Somalia		Thailand		Sweden
Tanzania		Tri. & Tobago		Switzerland
Togo		Uganda		U.K.
Tunisia		Venezuela		U.S.A.
		Zaire		W. Germany
		Zimbabwe		
(22)	(12)	(24)	(9)	(23)

Further tests indicate existence of possible thresholds in both sub-samples. For the sub-sample of 23 primary exports dependent countries, there are two second level threshold variables with significance at conventional level: initial output and initial literacy. Since initial output has the lowest P-value we report results based on initial output as the threshold variable. For the 23 primary-export dependent group, the point estimate for the initial output threshold is $\gamma = \$1410$ and divides this group into a high income group of 7 countries and a low income group of 16 countries.[8]

[8]Notice that since higher share of primary exports represents a lower level of development, the tree diagram are essentially inverted. Countries with lower shares are presented on top while those with higher shares take the lower branches.

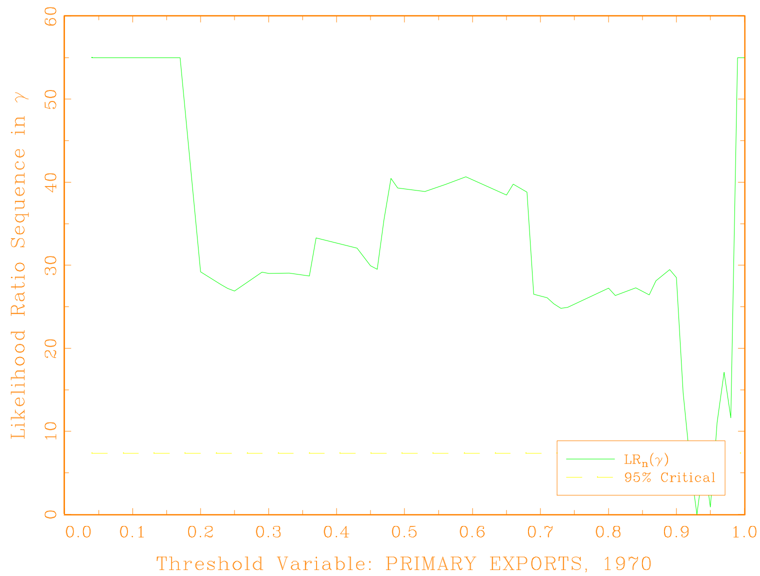

Figure 4.11: Sample split using share of primary commodities as threshold variable

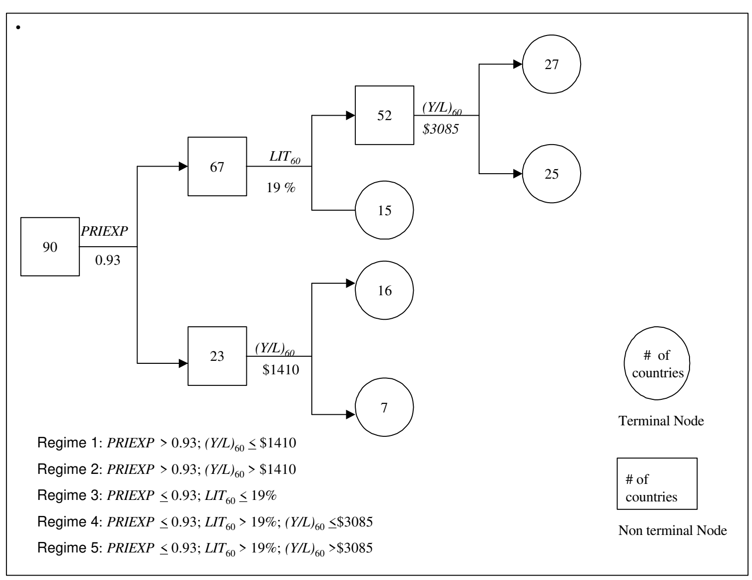

Figure 4.12: Threshold and regimes using share of primary exports as threshold variable

Table 4.6: Country classification using primary exports as threhold variable

Regime 1	Regime 2	Regime 3	Regime 4	Regime 5
Algeria	Burundi	Chile	Brazil	Argentina
Benin	Chad	Ecuador	Colombia	Australia
Cameroon	Cote d'Ivoire	Panama	Dom. Rep.	Austria
C. Afr. Rep.	Ethiopia	Papua N. Guinea	Egypt	Belgium
Congo	Ghana	Peru	El Slavado	Canada
Haiti	Liberia	Sri Lanka	Greece	Costa Rica
Mali	Malawi	Venezuela	Guatamala	Denmark
Morocco	Mauritania		Honduras	Finland
Mozambique	Niger		Hong Kong	France
Nepal	Nigeria		India	Ireland
Pakistan	Rwanda		Jamaica	Israel
Senegal	Somalia		Jordan	Italy
Sierra Leone	Sudan		Kenya	Japan
Tanzania	Togo		Madagascar	Mexico
Tunisia	Uganda		Malaysia	Netherlands
	Zambia		Paraguay	N. Zealand
			Phillipines	Nicaragua
			Portugal	Norway
			S. Korea	S. Africa
			Singapore	Spain
			Syria	Sweden
			Thailand	Switzerland
			Turkey	Tri. & Tobago
			Zaire	U.K.
			Zimbabwe	U.S.A.
				Uruguay
				W. Germany
(15)	(16)	(7)	(25)	(27)

In addition, the 67 countries whose share of primary commodities was less than 0.93 can further be split using initial literacy rates which obtain significant test results for a threshold (P-value = 0.090) with an implied point estimate for the threshold of $\hat{\gamma} = 19\%$ and a wide asymptotic confidence interval of $[14\%, 90\%]$. Initial literacy splits the 67 countries into two groups. The first comprises 15 low literacy countries and the second comprises the remaining 52 countries with literacy rate above 19%.

Finally, even the 52 countries with higher literacy rates can be distinguished by level of income. Using the initial literacy rate, the point estimate for the threshold is $\gamma = \$3085$, and divides the sub-sample that is less dependent on primary exports into a high-literacy low-income group of 25 countries and a high-income high literacy group of 27 countries. In total we have five regimes. As indicated before, regimes 1, 2 ad 5 are relatively stable. It's the middle income group that has a tendency to change significantly. Figure 4.12 and Table 4.6 show the tree diagram and list of the countries in the five regime respectively.

Since there were two second level threshold variables with significant P-value, we tested the alternative model which used initial literacy (instead of output) to divide the 23 country primary-export dependent group. The point estimate for the initial literacy threshold is $\gamma = 29\%$ and divides this group into a low literacy group of 14 and a high literacy group of 9 countries. These results are presented in the appendix D. Figure D4 shows the tree diagram while Table D3 is the country classification.

4.5 Regression Results

In order to illustrate the parameter heterogeneity revealed from the preceeding exercise, we estimated regression models for the baseline regimes implied by models estimated using initial output and initial literacy rates as first level threshold variables.

Tables 4.7 illustrates the extent of this parameter heterogeneity and underscores the futility of the search for generalizable propositions in global growth regression. When we use initial output as the primary threshold variable, both the signs and magnitudes of the contribution of different regressors varies across regime. For instance, the restricted models (lower part of Table 4.7) show that the share of physical capital (α) varies from 0.1778 in the high-income, high-literacy countries to 0.7738 in the high-income, low-literacy group. Similarly the share of human capital (β) is significant in regime 2 and 4 while it is meaningless for regimes 1 and 3.

Similar conclusions are reached when we estimate regressions using regimes implied by initial literacy rate. Table 4.8 demonstrates considerable variability in both the signs, magnitudes and statistical significance among the regression coefficients across regimes. The share of physical capital varies from 0.1404 in rich countries to 0.4807 in regime 4, while the share of human capital varies from as low as 0.0335 and insignificant in regime 2 to 0.2996 and statistically significant in regimes 1 and 4. Given this variability is size and composition of regimes, the size, magnitude and signs of the implied coefficients, these results caution against averaging over this heterogeneity in favor of analyzing determinants of growth on a regime by regime basis.

4.6 Discussion

The empirical results presented above represent the three categories of initial conditions. The first category, *initial level of economic development*, was captured by GDP_{60}, PRIEXP_{70}, and the urbanization rate in 1960 (URB_{60}) for which we reported results for the first two measures. The second type, *initial level of human capital* development, include initial literacy (LIT_{60}), gross enrollment in primary (P_{60}),

Table 4.7: Regression results for regimes derived using initial output.

Specification	Regime 1	Regime 2	Regime 3	Regime 4
Unrestricted				
Constant	3.3444 (1.8939)	0.3759 (1.738)	-2.7569^{***} (0.8973)	3.0510^{***} (1.0644)
$\ln(GDP60)$	-0.5569^{**} (0.2068)	-0.1754 (0.1626)	-0.5851^{***} (0.1164)	-0.5773^{***} (0.0918)
$\ln(Inv)$	0.2538^{***} (0.0682)	0.1005 (0.2310)	1.0025^{***} (0.1117)	0.5170^{***} (0.1794)
$\ln(n+g+\delta)$	-0.0661 (0.5313)	-0.3306 (0.4841)	2.5095^{***} (0.3956)	0.1168 (0.4190)
$\ln(school)$	-0.9075 (0.1026)	0.4529^{***} (0.1218)	-0.1285 (0.0957)	0.3735 (0.2465)
Std. Error	0.279	0.323	0.170	0.247
Adj. R^2	0.543	0.503	0.822	0.563
Obs.	15	27	20	28
Restricted				
Constant	6.5457^{***} (0.2382)	7.9962^{***} (0.3359)	7.3741^{***} (0.2159)	8.6783^{***} (0.3267)
Implied α	0.2079^{***} (0.1359)	0.7738 (0.1332)	0.5677^{***} (0.0951)	0.1778^{*} (0.1053)
Implied β	-0.0063 (0.0523)	0.3417^{***} (0.0876)	-0.1103 (0.1107)	0.3211^{***} 0.1027
Std. Error	0.201	0.455	0.333	0.324
Adj. R^2	0.264	0.479	0.529	0.380
Obs.	15	27	20	28

Notes: *** Significantly different from 0 at the 1% level. ** Significantly different from 0 at the 5% level. * Significantly different from 0 at the 10% level.

Table 4.8: Regression results for regimes derived using initial literacy.

Specification	Regime 1	Regime 2	Regime 3	Regime 4	Regime 5
Unrestricted					
Constant	1.5939	0.5656	-2.4936^{**}	-2.6209	3.2930^{***}
	0.9409	(2.7482)	(1.1196)	(1.5200)	(0.7402)
$\ln(GDP60)$	-0.3213^{**}	-0.2201	-0.2195^{***}	-0.0571	-0.4253^{***}
	(0.1318)	(0.2633)	(0.0660)	(0.1207)	(0.0497)
$\ln(Inv)$	0.3618^{**}	0.2322^{**}	1.1664^{***}	-0.3300	0.1501
	(0.1258)	(0.0901)	(0.1781)	(0.1678)	(0.1902)
$\ln(n+g+\delta)$	-0.1305	0.2536	0.9974^{**}	2.1538^{***}	0.0774
	(0.4475)	(1.0347)	(0.4769)	(0.4071)	(0.3706)
$\ln(school)$	0.3740^{***}	-0.2118^{*}	-0.3648^{***}	0.1499	0.2517^{**}
	(0.1014)	(0.0911)	(0.1250)	(0.0865)	(0.1083)
Std. Error	0.278	0.236	0.2401	0.204	0.183
Adj. R^2	0.608	0.339	0.7492	0.596	0.611
Obs.	22	12	24	9	23
Restricted					
Constant	7.7498^{***}	6.7346^{***}	7.4653^{***}	7.1743^{***}	8.9498^{***}
	(0.1827)	(0.1847)	(0.3188)	(0.2680)	(0.4389)
Implied α	0.1410	0.2817^{***}	0.4807^{***}	0.2355^{**}	0.1404
	(0.0883)	(0.0946)	(0.1353)	(0.1043)	(0.1834)
Implied β	0.2995^{***}	0.0335	0.0708	0.2996^{***}	0.2408^{*}
	(0.0754)	(0.0786)	(0.1345)	(0.1032)	(0.1354)
Std. Error	0.379	0.326	0.554	0.308	0.360
Adj. R^2	0.584	0.280	0.537	0.512	0.114
Obs.	22	12	24	9	23

Notes: *** Significantly different from 0 at the 1% level. ** Significantly different from 0 at the 5% level. * Significantly different from 0 at the 10% level.

secondary (S_{60}) and higher education (H_{60}), and life expectancy $(LIFE)$. In this group we reported results pertaining to literacy rates, gross enrollment in primary and higher education. The third type of variable, *natural conditions,* include location (LAT), the country's land area $(LAND)$, and the ethno-linguistic composition of the population $(ETHNO)$. Since none of the variables in this group had significant first level threshold effects, no results for this group were reported. However, we discuss below the implications of the second and third level interactions with other variables.

$(\mathbf{Y/L})_{60}$: Per capita output has a significant P-value $= 0.078$. The role of initial output in affecting economic development paths between groups of countries can be easily understood in terms of *vicious cycles of poverty* and poverty traps. Consider the group of 15 poorest countries. From a supply perspective, according to Engels households in low-income nations spend a larger share of their incomes on consumption, resulting in low savings. The low savings rate, in turn, results in low investment in physical capital hence low output. From a demand perspective, vicous cycles originate from the low per capita income which implies insufficient effective demand for goods and services, which in turn, result in small markets and discourages investors. As a result, low initial per capita income can trap poor countries because it stifles investment resulting in low initial and subsequent stocks of physical capital and, more importantly low growth..

A similar logic applies to initial literacy rates. The economic growth literature uses initial literacy as a proxy for the initial stock of human capital. The threshold effect of literacy implies that low initial stocks of human capital can significantly constrain a nation's growth capacity by reducing the nation's short and long term capacity to develop or adopt more efficient production techniques. The findings suggests that countries with low levels of human capital development will be trapped in low development trap since both the social and private returns to human capital investment seem to depend positively on the average quality of existing human capital (Azariadis and Drazen, 1990). In other words, economies with more well trained and qualified workers should grow faster than those with relatively less qualified workers. However, notice that the literacy rate encompasses primary, secondary and higher institutions of learning. If we break literacy down, we find a striking result that the most important component turns out to be primary education enrollment.

Gross enrollment in primary school had the most significant threshold effect (i.e. highest P-value) of all the threshold variables (P-value = 0.001). In contrast, secondary school enrollment ($\mathbf{S}_{60}$) had no significant first-level threshold effects (P-value = 0.129). Recall that our measure of initial literacy is defined as the fraction of the working age population that could read and write. In 1960, the reading, writing and numeracy skills obtained in primary schools were sufficient to make citizens functionally literate.

Another component of literacy rates that had significant P-value was gross enrollment in higher education. A threshold based on gross enrollment in higher education should be thought of as a reflection of bottlenecks in administrative capacity. A nation's lack of professional and administrative capacity will undoubtedly affect the efficiency of its public and private sectors. Notice that although higher education enrollment in 1960 has a significant threshold effect, the threshold occurs at zero. That is, in 1960 most poor countries had statistically negligible enrollments in institutions of higher learning. As a results, economies which start off with deficient administrative capacity will experience little and sporadic growth and are likely to converge to a low per capita income steady state while countries with higher enrollments can sustain growth over the long-run since they have the professional and administrative capacity.

Initial life expectancy also has significant threshold effects. In general, life expectancy, as a measure of longevity, reflects investment in the education and health sectors. There is a high international correlation between life expectancy and living standards. However, low initial life expectancy traps poor nations in a vicious circle by distorting a nation's collective sense of time preferences. Due to a low level of investment in public health, life cycles are brief and planning horizons are short, which in turn contributes to lower private investment and perpetual poverty (Azariadis, 2001). This is especially true in Africa, which drives the international correlation between life expectancy and standards of living, and where average life expectancy is two-thirds that of the developed nations.

The share of primary commodities in output or exports reflects the degree of sophistication of the economy. According to the stages of growth-type models, in the course of economic development, economies move away from heavy reliance on primary commodities towards manufacturing and services. Threshold effects based on primary commodities are especially crucial because they capture the role of the composition of exports, which in turn, captures the role of international terms of trade faced by a nation. It is likely that nations which rely on primary commodities will grow slowly. According to the Prebisch-Singer hypothesis, developing countries are trapped in low development traps because they face a circular deterioration of terms trade. In addition, heavy reliance on primary commodities has significant bearing on nature and composition of investment, which in turn may render the economy less flexible to changes in the international economy.

Perhaps a more interesting finding was that geography is not destiny. Neither the country's land area, its location nor the ethnolinguistic composition exhibit any significant threshold effects. In the case of area, which affects potential scale effects and potential market size, relatively small countries with sound policies, for instance, Hong Kong and Singapore, have managed to grow fast while establishing international markets. In contrast some large countries which implemented misguided policies, like India and Brazil, have experienced low growth.

4.7 Conclusion

This essay set out to accomplish two things. First was to investigate whether initial conditions can create history-dependent growth paths. Second was to investigate the extent to which initial and natural conditions preserve and augment initial inequality in income per capita among otherwise identical nations.

On the first objective, we established that, indeed, initial conditions have threshold effects. Our results accord with earlier findings by Durlauf and Johnson (1995) and Hansen (2000). In addition, our additional threshold variables extended the thresholds implied by the baseline model of Hansen (2000). In general, irrespective of first level threshold variable, a group of 30-34 low income countries seem to be in a low development trap and in most cases constituted the poorest regimes. Similarly, another group of 23-27 countries, mostly western industrialized nations consistently converged to a high development basin.

Specifically, the evidence presented confirms the high international correlation between initial stocks of human capital and the growth rate of per capita output. Notice that in the initial round of threshold estimation all three measures of human capital discussed in this essay gave similar results. Initial literacy splits the sample into a group of 34 low-literacy countries and 56 high-literacy countries while gross enrollment in primary (high) education divides the sample into two regimes comprising 33 (32) countries low enrolment countries and 57 (58) high enrollment nations, respectively. In addition, after three rounds of threshold estimation, all three threshold variables show that among the nations with high initial stock of human capital, there is a sub-sample of 23-25 fast growing countries.

Similarly, there is evidence that the initial level of economic development is crucial in determining a country's subsequent growth path. Whether we use initial output or the share of primary commodoties in exports, the threshold implications at the low and high end of the distribution are the same. Notice that both of these variables give, as the first regime, a group comprising 15 slow-growing, mostly African countries, and a regime of 27 (28 for PRIEXP70) rich countries, mostly western countries. In other words, economic growth in developed (poor) countries seems to be both faster (slower) and more predictable. The implication of this result is that not only is the level of initial output important, but the composition of output and exports, also matter. Both the level of output (measured by initial GDP) and the composition, (measured by the share of primary commodities in exports) can create history-dependent growth paths.

On the second objective, the results suggest that threshold effects associated with natural conditions are conditional. Notice that at the first level of sample splitting there is no evidence in support of any of the natural or geographical variables. However, latitude and ethnolinguistic diversity exhibit significant threshold effects in later rounds of threshold estimation, implying that its threshold effects are conditional on initial level of development or stocks of human capital. The moral of the results for natural conditions seems to be that neither land area, absolute latitude nor ethnolinguistic composition of the country predestinate a country's growth prospects. However, conditional on a country's initial economic development and stocks of human capital, two otherwise identical economies face different growth prospects depending on whether one lies in the tropics or whether the people are ethnically homogeneous. Controlling for human capital, more homogeneous nations and countries located in temperate regions seem to grow faster than ethnically heterogeneous nations or identical economies with a tropical location.

Chapter 5
Conclusion

This dissertation set out investigate the following: (i) the role of the specification of the production function in explaining cross-country variations in the level and growth rate of per capita income; (ii) whether determinants of growth in Africa are the same as elsewhere; (iii) the role of initial conditions in affecting long run growth in per capita output. The first essay, *Solow Model with CES Technology*, tested whether the data bear out a Cobb-Douglas relationship and found that it was rejected in favor of the more general CES specification.The main implication of this result is that essentially most growth models are misspecified.

We, therefore, proposed the nonlinear CES specification of the production function for the modelling coefficient hetergeneity and nonlinearities in the basic and extended Solow growth models. Given this framework, we showed that the basic and extended Solow Models with CES technology demonstrate more parameter homogeneity than is implied by the Cobb-Douglas specification. Under the CES we get more regimes and, contrary to postulations of standard growth models, regression coefficients vary across regimes. These results accord several empirical studies which find strong evidence is favor of parameter heterogeneity notwithstanding their different methodological approaches. However, this also implies that nonlinearity of the production function does not eliminate, or explain, parameter heterogeneity

The second essay, *Determinants of Economic Growth in Africa*, investigated factors underlying Africa's slow economic growth. In so doing we also investigated whether these determinants are sufficiently different from those explaining global economic development as to warrant a separate theory of African economic growth. Our results reject the assertion that African growth can be explained in terms of factors that are important for global economic growth but are lacking in Africa. Most variables that are important in the global sample lose their explanatory power in the Africa-only sample. In addition, results of posterior model probabilities suggest that the combination of variables relevant for explaining African growth differs from combinations that are important for global economic growth.

These implications are further born out in the medium term. In the adjustment period we also rejected the null hypothesis that determinants of growth in Africa were the same as those elsewhere. However, in the medium term while there was some evidence for institutional factors (Freedoms) and geographical factors (drought and being landlocked), the majority of regressors with high posterior probability were policy related. In varying degrees our findings concur and contrasts with those who argue that Africa's slow growth can be explained in terms of the institutional variables, and those who argue that good policies and institutions would significantly improve Africa's economic performance.

The third essay, *Initial Conditions as Threshold Variables in Economic Development,* investigates the role of initial conditions in economic growth. Specifically, we tested the *historical view* argues that "cross-country growth would be fundamentally same except for differences in history, e.g. in the circumstances from which the growth process begins". The evidence presented illustrated the high international correlation between initial stocks of human capital and the growth rate of per capita output. In the initial round of threshold estimation all three measures that we report gave similar results. Initial literacy split the sample into a group of 34 low-literacy countries and 56 high-literacy countries while gross enrollment in primary (high) education divided the sample into two regimes comprising 33 (32) countries low enrolment countries and 57 (58) nations respectively. In addition after three rounds of threshold estimation, all three threshold variables also show that among the nations with high initial stock of human capital, there is a sub-sample of 23-25 fast growing countries.

Similarly, the evidence also shows that the initial level of economic development is crucial in determining a country's growth path. Whether we use initial output or the share of primary export, the threshold implications at the low and high end are the same. Notice that both variables give, as the first regime, a group comprising 15 slow-growing, mostly African countries, and a regime of 27 (28 for PRIEXP70) rich countries, mostly western countries. In other words, economic growth in developed (poor) countries seems to be both faster (slower) and more predictable. This is important because it suggests that initial output and/or its composition create a history-dependent growth paths.

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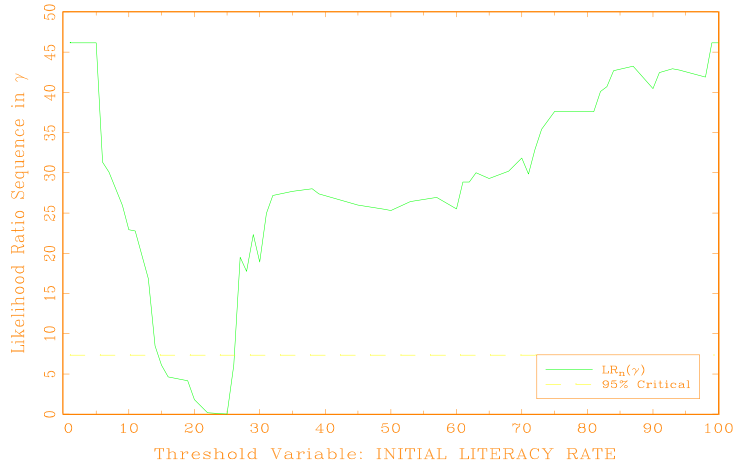
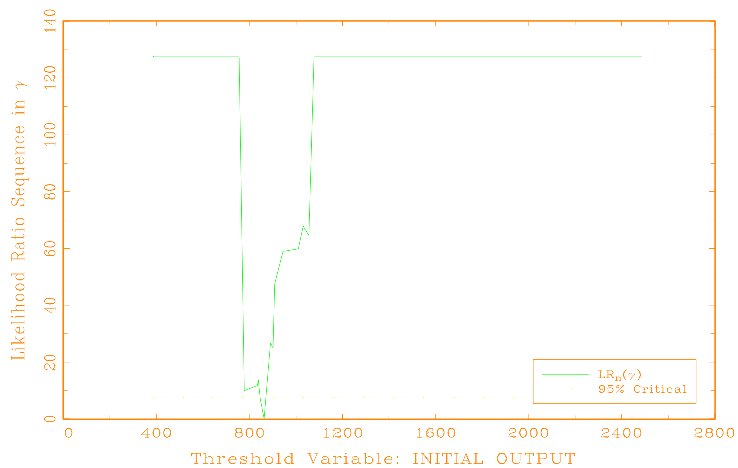
Appendix A

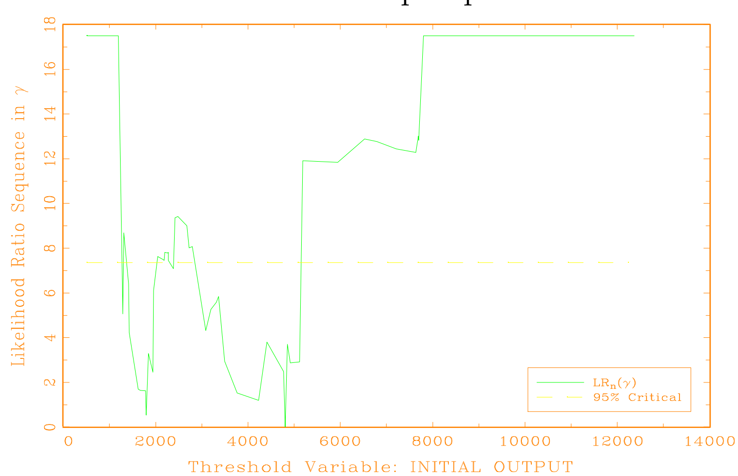
Results from Alternative Threshold Model Using Literacy Rate



First sample split



Second sample split



Third sample split

Figure A1 : Likelihood ratio statistic as functions of threshold variables

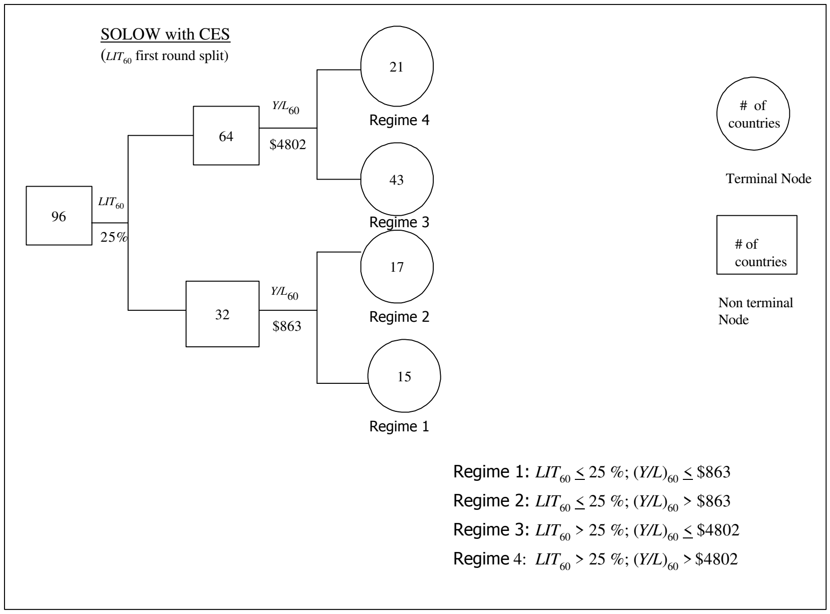


Figure A2: Threshold estimation in the Solow-CES model using literacy

Table A1: Country classification in four regimes (alternative splitting)

Regime 1	Regime 2	Regime 3		Regime 4
B. Faso	Algeria	Bolivia	Malaysia	Argentina
Bangladesh	Angola	Brazil	Mexico	Australia
Burundi	Benin	Burma	Nicaragua	Austria
C. Afri. Rep.	Cameroon	Colombia	Panama	Belgium
Ethiopia	Chad	Costa Rica	Papua N. G.	Canada
Liberia	Congo	Dom. Rep.	Paraguay	Chile
Malawi	Haiti	Ecuador	Peru	Denmark
Mali	I. Coast	Egypt	Philippines	Finland
Mauritania	Kenya	El Salvador	Portugal	France
Nepal	Morocco	Ghana	S. Africa	Italy
Niger	Mozambique	Greece	S. Korea	N. Zealand
Rwanda	Nigeria	Guatemala	Singapore	Netherlands
Sierra Leone	Pakistan	Honduras	Spain	Norway
Tanzania	Senegal	Hong Kong	Sri Lanka	Sweden
Togo	Somalia	India	Syria	Switzerland
	Sudan	Indonesia	Thailand	Tri. & Tobago
	Tunisia	Ireland	Turkey	U.K.
		Israel	Uganda	U.S.A.
		Jamaica	Zaire	Uruguay
		Japan	Zambia	Venezuela
		Jordan	Zimbabwe	W. Germany
		Madagascar		
(15)	(17)	(43)		(21)

Table A2: Cross-country growth regressions for the four regimes (alternative splitting)

Specification	Regime 1	Regime 2	Regime 3	Regime 4
Unrestricted				
Constant	5.2380***	3.9052***	−1.8288*	−0.9464
	(0.9456)	(0.4993)	(1.0889)	(1.1087)
$\ln(Y/L)_{i,60}$	−0.6578***	1.0256**	−0.1310	0.2750*
	(0.1077)	(0.4293)	(0.0813)	(0.1327)
$\ln s_{ik}$	−0.3098**	−0.7873**	2.6145***	1.9214***
	(0.1264)	(0.0957)	(0.4091)	(0.6145)
$\ln s_{ih}$	0.9479***	1.0905***	−1.2893***	−1.4007*
	(0.1672)	(0.2789)	(0.3092)	(0.7358)
$\ln(n_i + g + \delta)$	−0.5614	−0.6074*	−0.3967	−1.7911***
	(0.3236)	(0.3302)	(0.6866)	(0.1832)
$[\ln s_{ik} - \ln(n_i + g + \delta)]^2$	−0.1165	0.1628	−0.1853	−0.0089
	(0.1132)	(0.1097)	(0.1702)	(0.1036)
$[\ln s_{ih} - \ln(n_i + g + \delta)]^2$	0.0821*	0.5607***	0.2876**	−0.1894
	(0.0438)	(0.0864)	(0.1384)	(0.3246)
$[\ln s_{ik} - \ln s_{ih}]^2$	0.1262***	−0.4325***	−0.6398***	−0.6986**
	(0.0299)	(0.1131)	(0.1050)	(0.2546)
s.e.e.	0.10	0.13	0.31	0.13
Adj. R^2	0.81	0.93	0.57	0.85
Obs.	15	17	43	21
Restricted				
Constant	6.4971***	5.0077***	0.7073	0.1241
	(1.0360)	(1.2012)	(0.8613)	(1.2307)
Implied α	0.1041***	0.0060	0.6551***	0.5129***
	(0.0433)	(0.0775)	(0.1902)	(0.1117)
Implied β	0.3368***	0.7727***	0.2442*	0.2437***
	(0.0966)	(0.0983)	(0.1441)	(0.0590)
Implied σ	1.3236†††	1.0810†††	1.0511	0.9861
	(0.0541)	(0.0229)	(0.0982)	(0.0256)
Obs.	15	17	43	21

Notes: α and β are distribution parameters of physical and human capital respectively. Standard errors are given in parentheses. The standard errors for α and β were recovered using standard approximation methods for testing nonlinear functions of parameters. White's heteroskedasticity correction was used. *** (†††) Significantly different from 0 (1) at the 1% level. ** (††) Significantly different from 0 (1) at the 5% level. * (†) Significantly different from 0 (1) at the 10% level.

Table A3: Shares from the *basic* and *extended Solow-CES models*

Country	Basic CES (PWT 4.0)	Extended CES (PWT 4.0)		Basic CES (PWT 6.0)	Extended CES (PWT 6.0)	
	$shr(K^*)$	$shr(K^*)$	$shr(H^*)$	$shr(K^*)$	$shr(K^*)$	$shr(H^*)$
Algeria	0.7479	0.2878	0.3295	0.6182	0.4024	0.2091
Angola	0.4642	0.2319	0.2879	0.5131	0.3709	0.1835
Benin	0.5693	0.2544	0.2860	0.4615	0.3542	0.1830
Botswana	0.7705	0.2917	0.3036	0.5987	0.3968	0.2007
Burkina Faso	0.6526	0.2706	0.2334	0.5036	0.3679	0.1595
Burundi	0.4528	0.2293	0.2287	0.4463	0.3490	0.1577
Cameroon	0.6132	0.2631	0.3186	0.4957	0.3654	0.1896
C. Afr. Rep.	0.5837	0.2573	0.2792	0.4420	0.3476	0.1777
Chad	0.4984	0.2395	0.2276	—	—	—
Congo	0.8038	0.2974	0.3221	0.6645	0.4152	0.2166
Egypt	0.6548	0.2710	0.3543	0.4760	0.3590	0.2191
Ethiopia	0.4483	0.2283	0.2650	0.4221	0.3407	0.1756
Ghana	0.5386	0.2481	0.3339	0.5071	0.3690	0.2053
I. Coast	0.5515	0.2507	0.2867	0.4904	0.3639	0.1871
Kenya	0.6439	0.2689	0.2934	0.5419	0.3799	0.1914
Liberia	0.7056	0.2803	0.2976	—	—	—
Madagascar	0.4960	0.2390	0.3046	0.3742	0.3232	0.1927
Malawi	0.6109	0.2626	0.2401	0.5636	0.3864	0.1712
Mali	0.5008	0.2400	0.2616	0.4968	0.3658	0.1759
Mauritania	0.7786	0.2931	0.2616	0.4522	0.3510	0.1782
Mauritius	0.6629	0.2725	0.3559	0.5746	0.3897	0.2143
Morocco	0.5165	0.2434	0.3187	0.5723	0.3890	0.2007
Mozambique	0.4592	0.2308	0.2445	0.3432	0.3113	0.1699
Niger	0.5546	0.2514	0.2322	0.4878	0.3629	0.1610
Nigeria	0.5908	0.2587	0.2974	0.4847	0.3618	0.1882
Rwanda	0.5006	0.2400	0.2232	0.4008	0.3331	0.1658
Senegal	0.5488	0.2507	0.2840	0.4807	0.3605	0.1844
Sierra Leone	0.5946	0.2594	0.2886	—	—	—
Somalia	0.6011	0.2607	0.2606	—	—	—
S. Africa	0.7299	0.2847	0.3109	0.5849	0.3928	0.2112
Sudan	0.6052	0.2615	0.2896	—	—	—
Tanzania	0.6658	0.2731	0.2308	0.6716	0.4172	0.1603
Togo	0.6434	0.2688	0.3079	0.4672	0.3561	0.1941
Tunisia	0.6205	0.2645	0.3285	0.6315	0.4061	0.2073
Uganda	0.3923	0.2149	0.2606	0.3347	0.3079	0.1754
Zaire	0.4762	0.2346	0.3194	0.4395	0.3467	0.1883
Zambia	0.8198	0.3000	0.2975	0.5908	0.3945	0.1900
Zimbabwe	0.7073	0.2806	0.3270	0.6643	0.4152	0.2000

Table A3: Shares from the *basic* and *extended Solow-CES models*, continued

Country	Basic CES (PWT 4.0)	Extended CES (PWT 4.0)		Basic CES (PWT 6.0)	Extended CES (PWT 6.0)	
	$shr(K^*)$	$shr(K^*)$	$shr(H^*)$	$shr(K^*)$	$shr(K^*)$	$shr(H^*)$
Bangladesh	0.4793	0.2353	0.3121	0.5387	0.3789	0.1945
Burma	0.6008	0.2607	0.3230	—	—	—
Hong Kong	0.6867	0.2769	0.3522	0.6979	0.4242	0.2131
India	0.6650	0.2729	0.3376	0.5600	0.3854	0.2073
Israel	0.7861	0.2944	0.3696	0.7085	0.4270	0.2216
Japan	0.9252	0.3169	0.3919	0.7779	0.4448	0.2295
Jordan	0.6666	0.2732	0.3780	0.5223	0.3738	0.2243
Korea	0.7244	0.2837	0.3746	0.7126	0.4281	0.2237
Malaysia	0.7185	0.2826	0.3516	0.6398	0.4084	0.2134
Nepal	0.4693	0.2331	0.3000	0.5448	0.3808	0.1971
Pakistan	0.5781	0.2561	0.3064	0.5522	0.3830	0.1924
Phillippines	0.6203	0.2644	0.3746	0.5891	0.3940	0.2222
Singapore	0.8284	0.3014	0.3680	0.7874	0.4471	0.2182
Sri Lanka	0.6360	0.2674	0.3648	0.5354	0.3779	0.2202
Syria	0.6346	0.2672	0.3638	0.5783	0.3908	0.2163
Thailand	0.6600	0.2720	0.3250	0.7098	0.4273	0.2093
Austria	0.8347	0.3025	0.3813	0.7632	0.4411	0.2288
Belgium	0.8294	0.3016	0.3895	0.7334	0.4335	0.2307
Denmark	0.8621	0.3069	0.3971	0.7606	0.4404	0.2326
Finland	0.9613	0.3225	0.4006	0.8018	0.4507	0.2331
France	0.8370	0.3069	0.3831	0.7457	0.4366	0.2268
Germany	0.8889	0.3112	0.3832	—	—	—
Greece	0.8864	0.3108	0.3773	0.7506	0.4379	0.2246
Ireland	0.8288	0.3015	0.3957	0.7313	0.4329	0.2336
Italy	0.8423	0.3037	0.3720	0.7539	0.4387	0.2221
Netherlands	0.8138	0.2990	0.3887	0.7262	0.4316	0.2300
Norway	0.8843	0.3105	0.3917	0.8306	0.4577	0.2302
Portugal	0.8128	0.2989	0.3602	0.7213	0.4303	0.2219
Spain	0.7291	0.2845	0.3750	0.7227	0.4307	0.2270
Sweeden	0.8483	0.3047	0.3806	0.7341	0.4336	0.2275
Switzerland	0.8852	0.3106	0.3476	0.7391	0.4349	0.2224
Turkey	0.7061	0.2804	0.3409	0.6163	0.4018	0.2087
U.K.	0.7721	0.2920	0.3890	0.6999	0.4247	0.2290

Table A3: Shares from the *basic* and *extended Solow-CES models*, continued

Country	Basic CES (PWT 4.0)	Extended CES (PWT 4.0)		Basic CES (PWT 6.0)	Extended CES (PWT 6.0)	
	$shr(K^*)$	$shr(K^*)$	$shr(H^*)$	$shr(K^*)$	$shr(K^*)$	$shr(H^*)$
Canada	0.7608	0.2900	0.3827	0.6833	0.4302	0.2253
Costa Rica	0.6043	0.2613	0.3473	0.5680	0.3878	0.2096
Dom. Rep.	0.6539	0.2708	0.3410	0.5495	0.3822	0.2056
El Salvador	0.4920	0.2381	0.3176	0.4842	0.3617	0.2022
Guatemala	0.5131	0.2427	0.2951	0.5032	0.3678	0.1910
Haiti	0.5198	0.2441	0.2960	—	—	—
Honduras	0.6011	0.2607	0.3162	0.5454	0.3810	0.1962
Jamaica	0.7438	0.2871	0.3897	0.6759	0.4183	0.2280
Mexico	0.6730	0.2744	0.3454	0.6471	0.4104	0.2133
Nicaragua	0.6064	0.2618	0.3383	0.5127	0.3708	0.2079
Panama	0.7554	0.2891	0.3800	0.6379	0.4079	0.2192
Tri. & Tobago	0.7297	0.2846	0.3723	0.5586	0.3849	0.2252
U.S.A.	0.7541	0.2889	0.3944	0.6143	0.4012	0.2236
Argentina	0.8038	0.2974	0.3435	0.6630	0.4148	0.2175
Bolivia	0.6125	0.2629	0.3354	0.5378	0.3786	0.2065
Brazil	0.7280	0.2843	0.3298	0.6579	0.4134	0.2029
Chile	0.8164	0.2995	0.3613	0.6118	0.4005	0.2179
Colombia	0.6629	0.2725	0.3431	0.5558	0.3841	0.2110
Ecuador	0.7443	0.2872	0.3537	0.6407	0.4087	0.2115
Paraguay	0.5574	0.2560	0.3277	0.5443	0.3806	0.2012
Peru	0.5773	0.2560	0.3589	0.6453	0.4100	0.2176
Uruguay	0.6478	0.2697	0.3711	0.6476	0.4106	0.2300
Venezuela	0.5459	0.2496	0.3454	0.6286	0.4053	0.2068
Australia	0.8459	0.3043	0.3779	0.7078	0.4268	0.2245
Indonesia	0.6376	0.2678	0.3297	0.5794	0.3911	0.2051
New Zealand	0.7631	0.2905	0.3925	0.6807	0.4196	0.2296
Papua N. G.	0.6662	0.2731	0.2796	0.5468	0.3814	0.1807

Appendix B

Derivation of Solow Model with CES Technology

Step-by-step derivation of the basic Solow-CES equation

To derive the *basic* and *extended Solow-CES equations* we use the definition of $\sigma = \frac{1}{1-\rho}$, as algebra is easier with ρ rather than σ. The aggregate production function is given by the CES specification

$$Y = [\alpha K^{\rho} + (1-\alpha)(AL)^{\rho}]^{\frac{1}{\rho}}. \qquad \text{(B1)}$$

Divide through by AL to obtain the production function in its intensive form

$$y = [\alpha k^{\rho} + (1-\alpha)]^{\frac{1}{\rho}}. \qquad \text{(B2)}$$

In the basic Solow model the law of motion of capital is given by

$$\dot{k} = sy - (n+g+\delta)k \overset{ss}{=} 0. \qquad \text{(B3)}$$

Substitute for y and solve for k^*, where $(*)$ denotes steady-state values

$$s[\alpha k^{\rho} + (1-\alpha)]^{\frac{1}{\rho}} = (n+g+\delta)k \qquad \text{(B4)}$$

$$[\alpha k^{\rho} + (1-\alpha)] = \left(\frac{n+g+\delta}{s}\right)^{\rho} k^{\rho}$$

$$(1-\alpha) = \left[\left(\frac{n+g+\delta}{s}\right)^{\rho} - \alpha\right] k^{\rho}$$

$$k^{\rho} = \frac{(1-\alpha)}{\left[\left(\frac{n+g+\delta}{s}\right)^{\rho} - \alpha\right]}$$

$$k^* = \left\{\frac{(1-\alpha)}{\left[\left(\frac{n+g+\delta}{s}\right)^{\rho} - \alpha\right]}\right\}^{\frac{1}{\rho}}. \qquad \text{(B5)}$$

Substituting for k^* into $y = [\alpha k^{\rho} + (1-\alpha)]^{\frac{1}{\rho}}$ gives

$$y^* = \left\{\alpha \frac{(1-\alpha)}{\left[\left(\frac{n+g+\delta}{s}\right)^{\rho} - \alpha\right]} + (1-\alpha)\right\}^{\frac{1}{\rho}}$$

$$
\begin{aligned}
&= \left\{(1-\alpha)\left[\frac{\alpha}{\left[\left(\frac{n+g+\delta}{s}\right)^{\rho}-\alpha\right]}+1\right]\right\}^{\frac{1}{\rho}} \\
&= \left\{\frac{(1-\alpha)\left(\frac{n+g+\delta}{s}\right)^{\rho}}{\left[\left(\frac{n+g+\delta}{s}\right)^{\rho}-\alpha\right]}\right\}^{\frac{1}{\rho}} \\
&= \frac{(1-\alpha)^{\frac{1}{\rho}}\left(\frac{n+g+\delta}{s}\right)}{\left[\left(\frac{n+g+\delta}{s}\right)^{\rho}-\alpha\right]^{\frac{1}{\rho}}} \\
&= \frac{\left(\frac{n+g+\delta}{s}\right)}{\left[\frac{1}{1-\alpha}\left(\frac{n+g+\delta}{s}\right)^{\rho}-\frac{\alpha}{1-\alpha}\right]^{\frac{1}{\rho}}} \\
&= \left[\frac{1}{1-\alpha}-\frac{\alpha}{1-\alpha}\left(\frac{s}{n+g+\delta}\right)^{\rho}\right]^{-\frac{1}{\rho}} \\
&= \left[\frac{1}{1-\alpha}-\frac{\alpha}{1-\alpha}\left(\frac{s}{n+g+\delta}\right)^{\frac{\sigma-1}{\sigma}}\right]^{-\frac{\sigma}{\sigma-1}}.
\end{aligned}
$$

The last expression of y^* is equation (2.3) in the text. Define $z = -\frac{\alpha}{1-\alpha}$ and $(1-z) = \frac{1}{1-\alpha}$ and rewrite y^* as

$$
y^* = \left[z\left(\frac{n+g+\delta}{s}\right)^{-\rho} + (1-z)\right]^{-\frac{1}{\rho}}. \tag{B6}
$$

A second order Taylor series expansion around $\rho = 0$ ($\sigma = 1$) as in Kmenta (1967) yields

$$
\begin{aligned}
\ln y &= z\ln\left(\frac{n+g+\delta}{s}\right) - \frac{1}{2}\rho z\,(1-z)\left[\ln\left(\frac{n+g+\delta}{s}\right)\right]^2 \\
&= -\frac{\alpha}{1-\alpha}\ln\left(\frac{n+g+\delta}{s}\right) + \frac{1}{2}\frac{\sigma-1}{\sigma}\frac{\alpha}{(1-\alpha)^2}\left[\ln\left(\frac{n+g+\delta}{s}\right)\right]^2,
\end{aligned}
$$

$$
\ln\left(\frac{Y}{L}\right) = \ln A\,(0) + gt + \frac{\alpha}{1-\alpha}\ln\left(\frac{s}{n+g+\delta}\right) + \frac{1}{2}\frac{\sigma-1}{\sigma}\frac{\alpha}{(1-\alpha)^2}\left[\ln\left(\frac{s}{n+g+\delta}\right)\right]^2.
$$

which is equation (2.4) in the text.

Step-by-step derivation of the extended Solow-CES equation

The aggregate production function is now given by the CES specification

$$Y = [\alpha K^{\rho} + \beta H^{\rho} + (1-\alpha-\beta)(AL)^{\rho}]^{\frac{1}{\rho}}. \tag{B7}$$

Dividing through by AL gives the intensive form

$$y = [\alpha k^{\rho} + \beta h^{\rho} + (1-\alpha-\beta)]^{\frac{1}{\rho}}. \tag{B8}$$

The laws of motion for physical and human capital are give respectively by

$$\dot{k} = s_k y - (n+g+\delta)k \tag{B9}$$

$$\dot{h} = s_h y - (n+g+\delta)h. \tag{B10}$$

Substituting (B8) into (B9) gives

$$\dot{k} = s_k \left[\alpha k^{\rho} + \beta h^{\rho} + (1-\alpha-\beta)\right]^{\frac{1}{\rho}} - (n+g+\delta)k \overset{ss}{=} 0$$

$$\alpha k^{\rho} + \beta h^{\rho} + (1-\alpha-\beta) = \left[\frac{(n+g+\delta)k}{s_k}\right]^{\rho}$$

$$\beta h^{\rho} + (1-\alpha-\beta) = \left[\left(\frac{n+g+\delta}{s_k}\right)^{\rho} - \alpha\right] k^{\rho}$$

$$k^{*} = \left[\frac{\beta h^{\rho} + (1-\alpha-\beta)}{\left(\frac{n+g+\delta}{s_k}\right)^{\rho} - \alpha}\right]^{\frac{1}{\rho}}. \tag{B11}$$

Similarly,

$$\dot{h} = s_h \left[\alpha k^{\rho} + \beta h^{\rho} + (1-\alpha-\beta)\right]^{\frac{1}{\rho}} - (n+g+\delta)h \overset{ss}{=} 0$$

$$\alpha k^{\rho} + \beta h^{\rho} + (1-\alpha-\beta) = \left[\frac{(n+g+\delta)h}{s_h}\right]^{\rho}$$

$$\alpha k^{\rho} + (1-\alpha-\beta) = \left[\left(\frac{n+g+\delta}{s_h}\right)^{\rho} - \beta\right] h^{\rho}$$

$$h^* = \left[\frac{\alpha k^\rho + (1-\alpha-\beta)}{\left(\frac{n+g+\delta}{s_h}\right)^\rho - \beta}\right]^{\frac{1}{\rho}}. \tag{B12}$$

Substituting (B12) into (B11) obtains

$$k^* = \left\{\frac{\alpha\beta k^\rho + \beta(1-\alpha-\beta) + (1-\alpha-\beta)\left[\left(\frac{n+g+\delta}{s_h}\right)^\rho - \beta\right]}{\left[\left(\frac{n+g+\delta}{s_h}\right)^\rho - \beta\right]\left[\left(\frac{n+g+\delta}{s_k}\right)^\rho - \alpha\right]}\right\}^{\frac{1}{\rho}}$$

$$k^\rho\left[\left(\frac{n+g+\delta}{s_k}\right)^\rho - \alpha\right] = \frac{\alpha\beta k^\rho + (1-\alpha-\beta)\left(\frac{n+g+\delta}{s_h}\right)^\rho}{\left(\frac{n+g+\delta}{s_h}\right)^\rho - \beta}$$

$$k^\rho\left[\left(\frac{n+g+\delta}{s_k}\right)^\rho - \alpha\right] - \frac{\alpha\beta k^\rho}{\left(\frac{n+g+\delta}{s_h}\right)^\rho - \beta} = \frac{(1-\alpha-\beta)\left(\frac{n+g+\delta}{s_h}\right)^\rho}{\left(\frac{n+g+\delta}{s_h}\right)^\rho - \beta}$$

$$k^\rho\left[\left(\frac{n+g+\delta}{s_k}\right)^\rho - \frac{\alpha\beta}{\left(\frac{n+g+\delta}{s_h}\right)^\rho - \beta} - \alpha\right] = \frac{(1-\alpha-\beta)\left(\frac{n+g+\delta}{s_h}\right)^\rho}{\left(\frac{n+g+\delta}{s_h}\right)^\rho - \beta}$$

$$k^\rho\left\{\frac{\left(\frac{n+g+\delta}{s_k}\right)^\rho\left[\left(\frac{n+g+\delta}{s_h}\right)^\rho - \beta\right] - \alpha\left(\frac{n+g+\delta}{s_h}\right)^\rho}{\left[\left(\frac{n+g+\delta}{s_h}\right)^\rho - \beta\right]}\right\} = \frac{(1-\alpha-\beta)\left(\frac{n+g+\delta}{s_h}\right)^\rho}{\left(\frac{n+g+\delta}{s_h}\right)^\rho - \beta}$$

$$k^\rho\left\{\left(\frac{n+g+\delta}{s_k}\right)^\rho\left[1 - \beta\left(\frac{n+g+\delta}{s_h}\right)^{-\rho}\right] - \alpha\right\} = 1-\alpha-\beta$$

$$k^\rho\left[\left(\frac{n+g+\delta}{s_k}\right)^\rho - \beta\left(\frac{s_h}{s_k}\right)^\rho - \alpha\right] = 1-\alpha-\beta.$$

Therefore,

$$k^* = \left[\frac{1-\alpha-\beta}{\left(\frac{n+g+\delta}{s_k}\right)^\rho - \beta\left(\frac{s_h}{s_k}\right)^\rho - \alpha}\right]^{\frac{1}{\rho}}. \tag{B13}$$

Similarly,

$$h^* = \left[\frac{1-\alpha-\beta}{\left(\frac{n+g+\delta}{s_h}\right)^\rho - \alpha\left(\frac{s_k}{s_h}\right)^\rho - \beta}\right]^{\frac{1}{\rho}}. \tag{B14}$$

Substituting (B13) and (B14) into the intensive production function $y = [\alpha k^\rho + \beta h^\rho + (1-\alpha-\beta)]^{\frac{1}{\rho}}$ yields the steady-state output per effective labor

$$
\begin{aligned}
y^* &= \left\{\alpha\left[\frac{1-\alpha-\beta}{\left(\frac{n+g+\delta}{s_k}\right)^\rho - \beta\left(\frac{s_h}{s_k}\right)^\rho - \alpha}\right] + \beta\left[\frac{1-\alpha-\beta}{\left(\frac{n+g+\delta}{s_h}\right)^\rho - \beta\left(\frac{s_k}{s_h}\right)^\rho - \beta}\right] + (1-\alpha-\beta)\right\}^{\frac{1}{\rho}} \\
&= \left\{(1-\alpha-\beta)\left[\frac{\alpha}{\left(\frac{n+g+\delta}{s_k}\right)^\rho - \beta\left(\frac{s_h}{s_k}\right)^\rho - \alpha} + \frac{\beta}{\left(\frac{n+g+\delta}{s_h}\right)^\rho - \beta\left(\frac{s_k}{s_h}\right)^\rho - \beta} + 1\right]\right\}^{\frac{1}{\rho}} \\
&= \left\{(1-\alpha-\beta)\left[\frac{\alpha\left(\frac{n+g+\delta}{s_h}\right)^\rho - \alpha^2\left(\frac{s_k}{s_h}\right)^\rho - \alpha\beta + \beta\left(\frac{n+g+\delta}{s_k}\right)^\rho - \beta^2\left(\frac{s_h}{s_k}\right)^\rho - \alpha\beta}{\left[\left(\frac{n+g+\delta}{s_k}\right)^\rho - \beta\left(\frac{s_h}{s_k}\right)^\rho - \alpha\right]\left[\left(\frac{n+g+\delta}{s_h}\right)^\rho - \alpha\left(\frac{s_k}{s_h}\right)^\rho - \beta\right]} + 1\right]\right\}^{\frac{1}{\rho}}.
\end{aligned}
$$

Expanding the denominator gives

$$
\frac{(n+g+\delta)^{2\rho}}{(s_h s_k)^\rho} - 2\beta\left(\frac{n+g+\delta}{s_k}\right)^\rho - 2\alpha\left(\frac{n+g+\delta}{s_h}\right)^\rho + 2\alpha\beta + \alpha^2\left(\frac{s_k}{s_h}\right)^\rho + \beta^2\left(\frac{s_h}{s_k}\right)^\rho.
$$

Bringing all the terms in over the denominator gives the following numerator:

$$
\frac{(n+g+\delta)^{2\rho}}{(s_h s_k)^\rho} - \beta\left(\frac{n+g+\delta}{s_k}\right)^\rho - \alpha\left(\frac{n+g+\delta}{s_h}\right)^\rho,
$$

or,

$$
(n+g+\delta)^\rho\left[\left(\frac{n+g+\delta}{s_h s_k}\right)^\rho - \frac{\beta}{s_k^\rho} - \frac{\alpha}{s_h^\rho}\right].
$$

Therefore,

$$
y^* = \left\{\frac{(1-\alpha-\beta)(n+g+\delta)^\rho\left[\left(\frac{n+g+\delta}{s_h s_k}\right)^\rho - \frac{\beta}{s_k^\rho} - \frac{\alpha}{s_h^\rho}\right]}{\left[\left(\frac{n+g+\delta}{s_k}\right)^\rho - \beta\left(\frac{s_h}{s_k}\right)^\rho - \alpha\right]\left[\left(\frac{n+g+\delta}{s_h}\right)^\rho - \alpha\left(\frac{s_k}{s_h}\right)^\rho - \beta\right]}\right\}^{\frac{1}{\rho}}.
$$

Multiply top and bottom by $(s_h s_k)^\rho$ to obtain

$$
\begin{aligned}
y^* &= \left\{\frac{(1-\alpha-\beta)(n+g+\delta)^\rho\left[(n+g+\delta)^\rho - \beta s_h^\rho - \alpha s_k^\rho\right]}{\left[(n+g+\delta)^\rho - \beta s_h^\rho - \alpha s_k^\rho\right]\left[(n+g+\delta)^\rho - \beta s_h^\rho - \alpha s_k^\rho\right]}\right\}^{\frac{1}{\rho}} \\
&= \left[\frac{(1-\alpha-\beta)(n+g+\delta)^\rho}{(n+g+\delta)^\rho - \beta s_h^\rho - \alpha s_k^\rho}\right]^{\frac{1}{\rho}} \\
&= \left[\frac{(1-\alpha-\beta)}{1-\beta\left(\frac{s_h}{n+g+\delta}\right)^\rho - \alpha\left(\frac{s_k}{n+g+\delta}\right)^\rho}\right]^{\frac{1}{\rho}} \\
&= \left[\frac{1-\beta\left(\frac{s_h}{n+g+\delta}\right)^\rho - \alpha\left(\frac{s_k}{n+g+\delta}\right)^\rho}{1-\alpha-\beta}\right]^{-\frac{1}{\rho}}
\end{aligned}
$$

$$= \left[\tfrac{1}{(1-\alpha-\beta)} - \tfrac{\beta}{(1-\alpha-\beta)}\left(\frac{s_h}{n+g+\delta}\right)^{\rho} - \tfrac{\alpha}{(1-\alpha-\beta)}\left(\frac{s_k}{n+g+\delta}\right)^{\rho}\right]^{-\frac{1}{\rho}}$$

$$= \left[\tfrac{1}{(1-\alpha-\beta)} - \tfrac{\alpha}{(1-\alpha-\beta)}\left(\frac{s_k}{n+g+\delta}\right)^{\frac{\sigma}{\sigma-1}} - \tfrac{\beta}{(1-\alpha-\beta)}\left(\frac{s_h}{n+g+\delta}\right)^{\frac{\sigma}{\sigma-1}}\right]^{-\frac{\sigma-1}{\sigma}} \quad \text{(B15)}$$

which is equation (2.5) in the text.

Define $a_0 = \frac{1}{(1-\alpha-\beta)}$, $a_1 = -\frac{\beta}{(1-\alpha-\beta)}$, and $a_2 = -\frac{\alpha}{(1-\alpha-\beta)}$ (note that $a_0 + a_1 + a_2 = 1$) and let $\bar{H} = \dfrac{s_h}{(n+g+\delta)}$, $\bar{K} = \dfrac{s_k}{(n+g+\delta)}$.

The production function can then be written as

$$y = \left(a_0 + a_1\bar{H}^{\rho} + a_2\bar{K}^{\rho}\right)^{-\frac{1}{\rho}}. \quad \text{(B16)}$$

Taking logs gives

$$\ln(y) = -\frac{1}{\rho}\ln\left(a_0 + a_1\bar{H}^{\rho} + a_2\bar{K}^{\rho}\right). \quad \text{(B17)}$$

Let

$$f(\rho) = \ln\left(a_0 + a_1\bar{H}^{\rho} + a_2\bar{K}^{\rho}\right). \quad \text{(B18)}$$

The second order Taylor series approximation of $f(\rho)$ around $\rho = 0$ obtains $f(\rho) \approx f(0) + \rho f'(0) + \frac{\rho^2}{2}f''(0)$:

$$f(0) = \ln(a_0 + a_1 + a_2) = \ln[1] = 0 \quad \text{(B19)}$$

$$f'(\rho) = \frac{a_1\bar{H}^{\rho}\ln\bar{H} + a_2\bar{K}^{\rho}\ln\bar{K}}{a_0 + a_1\bar{H}^{\rho} + a_2\bar{K}^{\rho}} \quad \text{(B20)}$$

$$f'(0) = \frac{a_1\ln\bar{H} + a_2\ln\bar{K}}{a_0 + a_1 + a_2} = a_1\ln\bar{H} + a_2\ln\bar{K}$$

$$= -\frac{\beta}{(1-\alpha-\beta)}\ln\frac{s_h}{(n+g+\delta)} - \frac{\alpha}{(1-\alpha-\beta)}\ln\frac{s_k}{(n+g+\delta)} \quad \text{(B21)}$$

$$f''(\rho) = \frac{\left(a_0 + a_1\bar{H}^{\rho} + a_2\bar{K}^{\rho}\right)\left[a_1\bar{H}^{\rho}\left(\ln\bar{H}\right)^2 + a_2\bar{K}^{\rho}\left(\ln\bar{K}\right)^2\right] - \left(a_1\bar{H}^{\rho}\ln\bar{H} + a_2\bar{K}^{\rho}\ln\bar{K}\right)^2}{\left(a_0 + a_1\bar{H}^{\rho} + a_2\bar{K}^{\rho}\right)^2} \quad \text{(B22)}$$

$$f''(0) = \frac{(a_0 + a_1 + a_2)\left[a_1\left(\ln \bar{H}\right)^2 + a_2\left(\ln \bar{K}\right)^2\right] - \left(a_1 \ln \bar{H} + a_2 \ln \bar{K}\right)^2}{(a_0 + a_1 + a_2)^2}. \tag{B23}$$

Expanding the numerator of equation (B23) gives

$$a_0\left[a_1\left(\ln \bar{H}\right)^2 + a_2\left(\ln \bar{K}\right)^2\right] + a_1^2(\ln \bar{H})^2 + a_1a_2(\ln \bar{K})^2 + a_2^2(\ln \bar{K})^2 + a_1a_2(\ln \bar{H})^2 - a_1^2\left(\ln \bar{H}\right)^2 - a_2^2\left(\ln \bar{K}\right)^2 - 2a_1a_2\left(\ln \bar{K}\ln \bar{H}\right).$$

Hence,

$$f''(0) = \frac{a_0a_1\left(\ln \bar{H}\right)^2 + a_0a_2\left(\ln \bar{K}\right)^2 + a_1a_2\left[\left(\ln \bar{K}\right)^2 - 2\ln \bar{K}\ln \bar{H} + \left(\ln \bar{H}\right)^2\right]}{(a_0 + a_1 + a_2)^2}. \tag{B24}$$

Using that $a_0 = \frac{1}{(1-\alpha-\beta)}$, $a_1 = -\frac{\beta}{(1-\alpha-\beta)}$, $a_2 = -\frac{\alpha}{(1-\alpha-\beta)} \Rightarrow a_0 + a_1 + a_2 = 1$ gives

$$f''(0) = -\frac{\beta}{(1-\alpha-\beta)^2}\left(\ln \bar{H}\right)^2 - \frac{\alpha}{(1-\alpha-\beta)^2}\left(\ln \bar{K}\right)^2 + \frac{\alpha\beta}{(1-\alpha-\beta)^2}\left(\ln \bar{K} - \ln \bar{H}\right)^2$$

$$f''(0) = -\frac{\beta}{(1-\alpha-\beta)^2}\left[\ln\left(\frac{s_h}{n+g+\delta}\right)\right]^2 - \frac{\alpha}{(1-\alpha-\beta)^2}\left[\ln\left(\frac{s_k}{n+g+\delta}\right)\right]^2 + \frac{\alpha\beta}{(1-\alpha-\beta)^2}\left[\ln\left(\frac{s_k}{s_h}\right)\right]^2. \tag{B25}$$

Substituting (B19), (B21) and (B25) in $f(\rho) = f(0) + \rho f'(0) + \frac{\rho^2}{2}f''(0)$, obtains

$$f(\rho) = \rho\left[-\tfrac{\alpha}{1-\alpha-\beta}\ln\left(\frac{s_k}{n+g+\delta}\right) - \tfrac{\beta}{1-\alpha-\beta}\ln\left(\frac{s_h}{n+g+\delta}\right)\right] - \tfrac{\rho^2\beta}{2(1-\alpha-\beta)^2}\left[\ln\left(\frac{s_h}{n+g+\delta}\right)\right]^2 - \tfrac{\rho^2\alpha}{2(1-\alpha-\beta)^2}\left[\ln\left(\frac{s_k}{n+g+\delta}\right)\right]^2 + \tfrac{\rho^2\alpha\beta}{2(1-\alpha-\beta)^2}\left[\ln\left(\frac{s_k}{s_h}\right)\right]^2. \tag{B26}$$

Finally, given that $\ln y = -\frac{1}{\rho}f(\rho)$ then

$$\ln y = \tfrac{\alpha}{1-\alpha-\beta}\ln\left(\frac{s_k}{n+g+\delta}\right) + \tfrac{\beta}{1-\alpha-\beta}\ln\left(\frac{s_h}{n+g+\delta}\right) + \tfrac{\rho\alpha}{(1-\alpha-\beta)^2}\left[\ln\left(\frac{s_k}{n+g+\delta}\right)\right]^2 + \tfrac{\rho\beta}{(1-\alpha-\beta)^2}\left[\ln\left(\frac{s_h}{n+g+\delta}\right)\right]^2 - \tfrac{\rho\alpha\beta}{(1-\alpha-\beta)^2}\left[\ln\left(\frac{s_k}{s_h}\right)\right]^2, \tag{B27}$$

or,

$$\ln\left(\tfrac{Y}{L}\right) = \ln A(0) + gt + \tfrac{\alpha}{1-\alpha-\beta}\ln\left(\frac{s_k}{n+g+\delta}\right) + \tfrac{\beta}{1-\alpha-\beta}\ln\left(\frac{s_h}{n+g+\delta}\right) + \tfrac{1}{2}\tfrac{\sigma-1}{\sigma}\tfrac{1}{(1-\alpha-\beta)^2}\left\{\alpha\left[\ln\left(\frac{s_k}{n+g+\delta}\right)\right]^2 + \beta\left[\ln\left(\frac{s_h}{n+g+\delta}\right)\right]^2 - \alpha\beta\left[\ln\left(\frac{s_k}{s_h}\right)\right]^2\right\}.$$

which is equation (2.6) in the text.

Appendix C

List of African Countries, Data and Results

Table C1: List of Countries and Initial Conditions

Country	**Growth**	**GDP60**	**LIFEXP60**	**PrSch60**
Angola	0.00	6.79	37.5	0.21
Benin	-0.01	7.02	38.90	0.27
Botswana	0.06	6.28	45.70	0.42
Burkina Faso	0.00	6.15	36.30	0.08
Burundi	0.00	6.38	41.80	0.18
Cameroon	0.01	6.55	43.40	0.65
Cent'l Afr. Rep.	-0.01	6.49	39.30	0.32
Chad	-0.02	6.50	34.90	0.17
Congo	0.02	6.97	47.30	0.78
Ethiopia	0.00	5.52	42.20	0.07
Gabon	0.02	7.49	40.90	1.00
Gambia	0.01	6.20	32.30	0.12
Ghana	0.00	6.77	45.20	0.38
Cote d'Ivoire	0.00	6.88	39.50	0.60
Kenya	0.01	6.46	45.00	0.47
Lesotho	0.04	5.66	47.70	0.83
Liberia	-0.01	6.55	41.50	0.31
Madagascar	-0.02	7.06	41.00	0.52
Malawi	0.01	5.91	37.90	0.67
Mali	0.00	6.20	35.90	0.10
Mauritania	0.00	6.75	35.30	0.08
Mauritius	0.02	7.94	59.40	0.98
Mozambique	-0.02	7.03	35.20	0.48
Niger	0.00	6.22	35.40	0.05
Nigeria	0.01	6.32	39.70	0.36
Rwanda	0.01	6.24	46.50	0.49
Senegal	0.00	6.92	39.60	0.27
Sierra Leone	0.01	6.94	31.50	0.23
Somalia	0.00	6.92	36.10	0.09
South Africa	0.01	7.65	49.20	0.89
Sudan	0.00	6.82	38.80	0.25
Tanzania	0.02	5.74	40.60	0.25
Togo	0.01	5.89	39.50	0.44
Uganda	-0.01	6.52	43.20	0.49
Zaire	-0.01	6.13	42.10	0.60
Zambia	-0.01	6.86	41.80	0.42
Zimbabwe	0.00	6.92	45.50	0.96

Table C2: Variable Definition and Sources

Variable	Definition	Source
Growth	Avg growth of GDP, 1985 international prices(1960 − 1992)	SH
GDP60	Log of level of real GDP in 1960	SH
Lifexp60	Life Expectancy at birth in 1960	WB
Prim60	Avg years of primary schooling in population over 25 in 1960	BL
OutOrie	Index of trade restriction	
Area	Size of country's land area in millions of square kilometers	Lee
Grop	Average growth of population (1960 − 1990)	SH
YearOpen	Fraction of years which the economy is ratedopen	SW
Revcoups	Avg number of revolutions and coups per year (1960 − 1984)	Banks
War	Dummy =1 if county participated in at least in one external war	Banks
PolRights	Index of Political Rights (ranges from 1-7 : 1= most freedom	BL
Civilib	Index of Civil Liberties (ranges from 1-7; 1= most freedom	BL
Abslat	Measure of distance form the equator	BL
Frac	Probability that two randomly selected people from a country will not belong to the same ethnic or linguistic group	TH
Primexp70	Share of exports of primary products in GDP in 1970	WB
Urban60	Fraction of population which lived in urban areas in1960	BL
RERD	Real exchange Rate distortion	BL
British	Dummy =1 if country is former British Colony	BL
French	Dummy =1 if country is former French colony	BL
Catholic	Fraction of Population Catholic	Barro
Hindu	Fraction of Population Hindu	Barro
Protestant	Fraction of Population Protestant	Barro
Muslim	Fraction of Population Muslim	Barro
Mining	Fraction of GDP in Mining	HJ
EconOrg	Type of Economic Organization: i.e of degree of capitalism	HJ
Other	Fraction speaking foreign language	Barro
English	Fraction speaking English language	Barro
Cons	Ratio of household Consumption to GDP	SH
Investment	Ratio of real domestic investment (public +private) to real GDP	SH
FinDepth	Average ratio of liquid liabilities of the financial system to GDP	WB
SHExch	Measure of Exchange Rate Distortion	BL
Openness	(Imports + Exports)/GDP	SH
Debt Stock	Debt stock as percentage of GDP	WB
Debt burden	Debt stock as percentage of export	WB
TotalODA	Overseas development assistance from all sources	Bates
Multi ODA	Multilateral overseas development assistance	Bates
Drought	Number of years country had a Drought(1980-1995)	WB
SAP	Fraction of 1980-1995 period that country was SAP compliant	

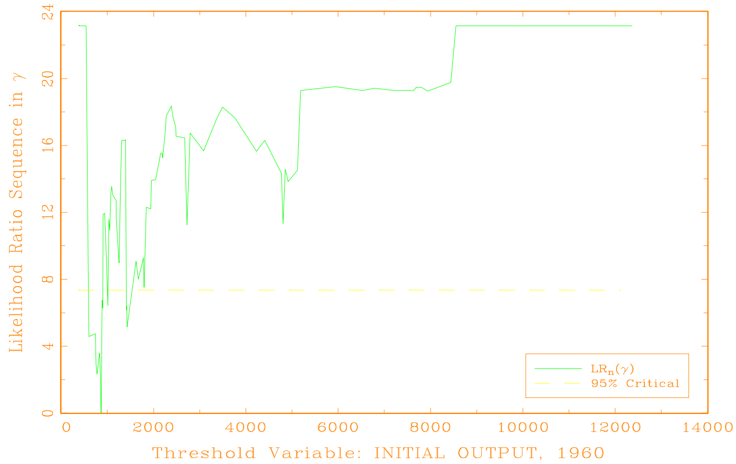
Notes: WB = World Bank, TH =Taylor and Hudson, HJ = Hall and Jones,
SH = Summers and Heston, BL =Barro and Lee, SW = Sachs and Warner.

Table C3: Robustness of Regressor Posterior Probability

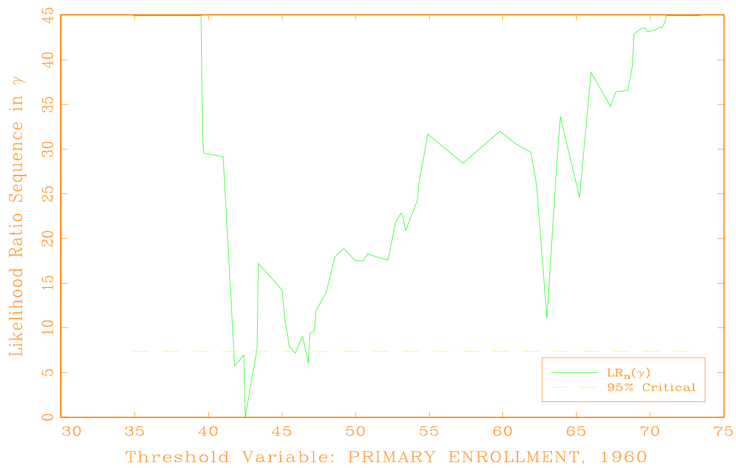
	Regressor	Small Sample	Large Sample
1	GDP level in 1960	0.994	0.998
2	Fraction of Mining in GDP	0.974	0.987
3	Primary Exports, 1970	0.777	0.921
4	Primary School Enrolment, 1960	0.606	0.731
5	Investment	0.609	0.583
6	Number of Years Economy open	0.682	0.455
7	Fraction Protestant	0.526	0.633
8	Outward Orientation	0.589	0.617
9	British Colony Dummy	0.525	0.669
10	Area (Scale Effect)	0.484	0.523
11	Revolutions and Coups	0.451	0.455
12	Fraction Muslim	0.379	0.460
13	population Growth	0.342	0.273
14	War Dummy	0.305	0.258
15	Fraction Catholic	0.266	0.298
16	Life Expectancy, 1960	0.249	0.518
17	French Colony Dummy	0.219	0.256
18	Political Rights	0.205	0.213
19	Exchange Rate Distortion	0.174	0.249
20	SAP	0.175	
21	Civil Liberties	0.141	0.247
22	English Speaking Fraction		0.457
23	Ethnolinguistic Fractionalization		0.320
24	Economic Organization		0.342
25	Fraction Speaking Foreign language		0.429
26	Fraction of Population Urban,1960		0.166
27	Government Expenditure		0.278
28	Openess		0.193
29	ODA		0.191

Appendix D

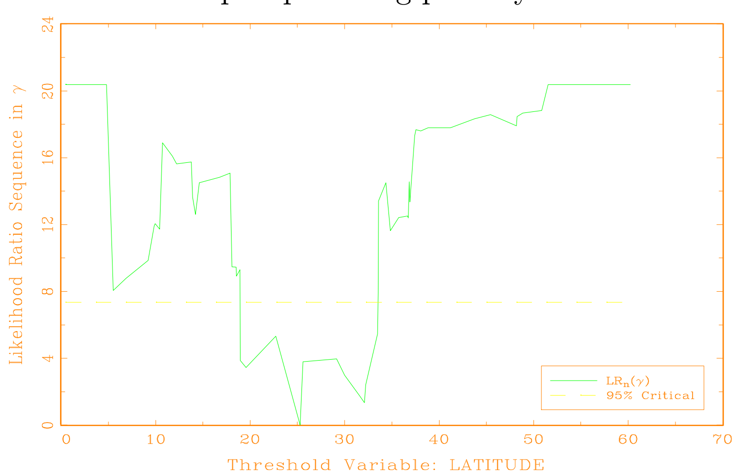
Initial Conditions and Alternative Thresholds



First sample split using output



Second sample split using primary enrollment



Third sample split using latitude

Figure D1: Likelihood ratio statistic as a function of threshold variables

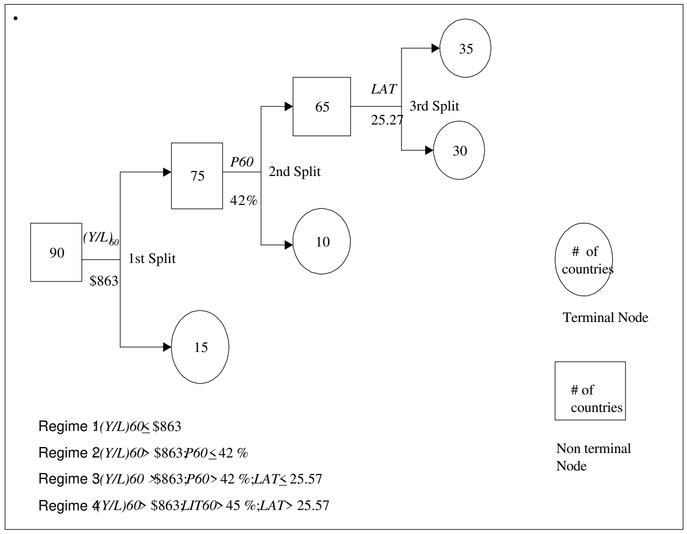


Figure D2: Tree Diagram in alternativr split uing $(Y/L)_{60}$

Table D1: Alternative country classification and regimes using initial output

Regime 1	Regime 2	Regime 3		Regime 4	
Burundi	Benin	Brazil	Kenya	Algeria	N. Zealand
C. Afr. Rep.	Chad	Cameroon	Madagascar	Argentina	Netherlands
Ethiopia	Ghana	Colombia	Malaysia	Australia	Norway
Liberia	Nigeria	Congo	Mexico	Austria	Paraguay
Malawi	Pakistan	Costa Rica	Mozambique	Belgium	Portugal
Mali	P.N. Guinea	Ivory Coast	Nicaragua	Canada	S. Africa
Mauritania	Senegal	Dom. Rep.	Panama	Chile	S. Korea
Nepal	Somalia	Ecuador	Peru	Denmark	Spain
Niger	Sudan	El Slavado	Phillipines	Egypt	Sweden
Rwanda	Zambia	Guatamala	Sri Lanka	Finland	Switzerland
Sierra Leone		Haiti	Thailand	France	Syria
Tanzania		Honduras	T.& Tobago	Greece	Tunisia
Togo		Hong Kong	Singapore	Ireland	Turkey
Uganda		India	Venezuela	Israel	U.K.
Zaire		Jamaica	Zimbabwe	Italy	U.S.A.
				Japan	Uruguay
				Jordan	Germany
				Morocco	
(15)	(10)	(30)		(35)	

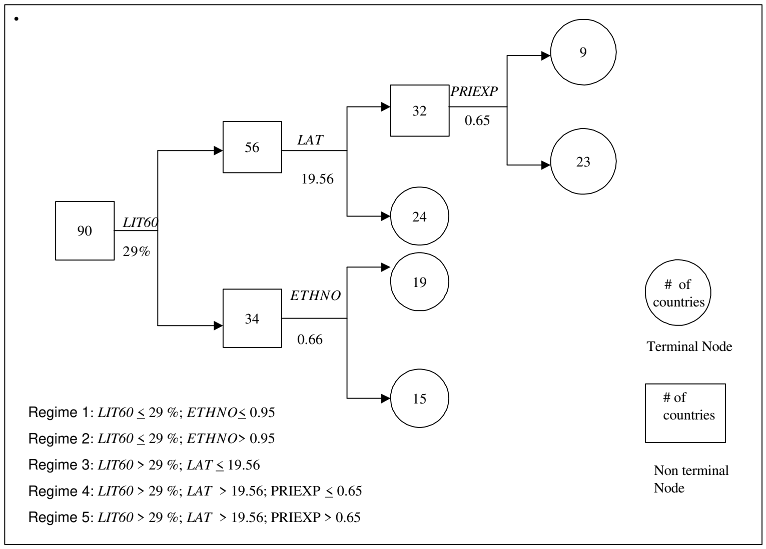


Figure D3: Tree diagram in alternate sample split (LIT60)

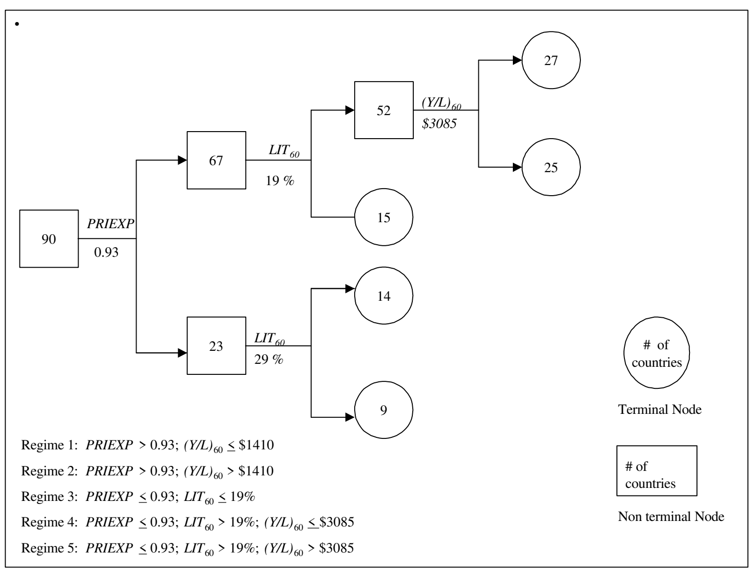


Figure D4: Tree diagram in alternative sample split (PRIEXP)

Table D2: Alternative country classification and regimes using literacy rate

Regime 1	Regime 2	Regime 3	Regime 4	Regime 5
Algeria	Cameroon	Brazil	Argentina	Austria
Benin	C. Afr. Rep	Colombia	Australia	Belgium
Burundi	Chad	Costa Rica	Chile	Canada
Congo	Cote d'Ivoire	Dom. Rep.	Jordan	Denmark
Egypt	Ethiopia	Ecuador	N. Zealand	Hong Kong
Haiti	Ghana	El Slavado	Paraguay	Finland
Malawi	India	Guatamala	Syria	France
Mauritania	Kenya	Honduras	Turkey	Greece
Morocco	Liberia	Jamaica	Uruguay	Ireland
Mozambique	Mali	Madagascar		Israel
Pakistan	Nepal	Malaysia		Italy
Papua N. Guinea	Niger	Mexico		Japan
Rwanda	Nigeria	Nicaragua		Netherlands
Somalia	Senegal	Panama		Norway
Tunisia	Sierra Leone	Peru		Portugal
	Sudan	Phillipines		S. Africa
	Tanzania	Singapore		S. Korea
	Togo	Sri Lanka		Spain
	Zambia	Thailand		Sweden
		Tri. & Tobago		Switzerland
		Uganda		U.K.
		Venezuela		U.S.A.
		Zaire		W. Germany
		Zimbabwe		
(15)	(19)	(24)	(9)	(23)

Table D3: Country classification using $PRIEXP_{70}$

Regime 1	Regime 2	Regime 3	Regime 4	Regime 5
Algeria	Burundi	Chile	Brazil	Argentina
Benin	Chad	Ecuador	Colombia	Australia
Cameroon	Cote d'Ivoire	Panama	Dom. Rep.	Austria
C. Afr. Rep.	Ethiopia	Papua N. Guinea	Egypt	Belgium
Congo	Ghana	Peru	El Slavado	Canada
Haiti	Liberia	Sri Lanka	Greece	Costa Rica
Mali	Malawi	Sudan	Guatamala	Denmark
Morocco	Mauritania	Uganda	Honduras	Finland
Mozambique	Niger	Venezuela	Hong Kong	France
Nepal	Nigeria		India	Ireland
Pakistan	Rwanda		Jamaica	Israel
Senegal	Somalia		Jordan	Italy
Sierra Leone	Togo		Kenya	Japan
Tanzania	Zambia		Madagascar	Mexico
Tunisia			Malaysia	Netherlands
			Paraguay	N. Zealand
			Phillipines	Nicaragua
			Portugal	Norway
			S. Korea	S. Africa
			Singapore	Spain
			Syria	Sweden
			Thailand	Switzerland
			Turkey	Tri. & Tobago
			Zaire	U.K.
			Zimbabwe	U.S.A.
				Uruguay
				W. Germany
(15)	(14)	(9)	(25)	(27)

Vita

Winford Henderson Masanjala, was born on January 28,1968, in Zomba, Malawi. He holds a Bachelor of Social Science degree from the University of Malawi, a Post-graduate diploma in population and development from the Institute of Social Studies, in the Hague, the Netherlands, and a Master of Science degree in economics from the Louisiana State University, at Baton Rouge, Louisiana.

Between 1991 and 1996 he worked in various capacities in the Ministry of Labor in the Malawi civil service. In 1996 he joined the University of Malawi as an assistant lecturer in economics and became a full lecturer in 1999. He also worked as a research assistant at the Louisiana State University's Center for Energy Studies and as a teaching assistant in the Department of Economics. He has taught a number of courses in Malawi and in the USA, including Economic Development and Planning, Money and Banking and Principles of Macroeconomics. His research interests lie mainly in the areas of economic growth and development, macroeconomics and monetary economics.