ON GROWTH AND INDEBTEDNESS WITH IMPERFECT CAPITAL MOBILITY

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THESIS SUBMITTED IN PARTIAL FULFILLMENT OF
THE REQUIREMENTS FOR THE DEGREE OF
DOCTOR OF PHILOSOPHY

in the Department
of
Economics

Simon Fraser University

September 1994

APPROVAL

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Degree: Ph.D. (Economics)

Title of Thesis: On Growth and Indebtedness With Imperfect Capital Mobility

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On Growth and Indebtedness With Imperfect Capital Mobility

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Abstract

Employing closed-economy models, recent cross-country growth literature seems to have confirmed the conditional convergence hypothesis (CCH): holding population growth and capital accumulation constant, poor countries tend to grow faster than rich countries. However, this literature reveals an empirical puzzle. African and Latin American countries grew systematically slower than the sample mean during the 1970s and 1980s.

This thesis reexamines the CCH under the assumption of open economies with imperfect capital mobility. Two alternative models are constructed. The first shows that the CCH can be extended to open economies if foreign borrowing can be used only to finance the accumulation of physical (but not human) capital. Furthermore, external variables such as debt and openness are expected to affect growth, either directly, or indirectly by affecting investment share.

The second model studies the growth of a small borrowing economy facing a credit ceiling internationally. This framework classifies a borrowing economy as one of three cases: never-constrained, ever-constrained and optimal-regime-switching. The key result is that growth paths of output, investment, and foreign debt for a regime-switching country exhibit kinks and different convergence properties. This attributes low growth rates in Africa and Latin America to excessive borrowing in the late 1970s and subsequent regime-switching.

Empirically, for 98 countries from 1960 to 1986, we find that openness has a positive effect on the growth rate while debt has a negative effect, and that CCH does indeed hold in an open-economy setting. Secondly, when growth and investment are both treated as dependent variables and reestimated in a simultaneous equation system, we find a significant negative effect of debt on investment share, and a much larger coefficient of investment on growth. We also reconfirm the two-link chain previously identified in the literature: openness is positively correlated with the investment share and is therefore growth-promoting. To allow for dynamic

variations across time, we further respecify the model in a pooled cross-sectional and time-series analysis, producing more efficient parameter estimates.

Finally, we propose a Logit model to determine the probability of a country's being credit constrained. We find that debt-service ratio, reserves-to-import ratio, average interest on the loans, lagged growth rate, lagged investment share, and share of government spending are important indicators of debt servicing capacity.

Acknowledgements

I would like to express my appreciation and intellectual indebtedness to my thesis committee, Professor Richard G. Harris, Professor Robert A. Jones, and especially my senior supervisor, Professor James W. Dean, for their consistent guidance and support throughout this work. Sincere thanks also go to Professor Robert Mundell of Columbia University for serving as the external examiner. All remaining errors and shortcomings are my responsibility.

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Chapter 1 Introduction

The purpose of this thesis is to study the relationship between a country's growth rate and its indebtedness and openness, a subject that has been overlooked in the growth literature. In a closed economy version of a neoclassical growth model such as Solow (1956), Cass (1965) and Koopmans (1965), international factor mobility and trade are completely ruled out. The growth rate is determined simply by exogenous parameters such as the rate of population growth, accumulation rates of human and physical capital, and the rate of technological progress. Hence a conditional convergence hypothesis (CCH) follows: holding saving rates for physical and human capitals, and population growth constant, countries grow faster per capita if their initial income levels are further below their steady state positions, because of diminishing returns on accumulating capital.

By contrast, small open economy growth models, such as Blanchard and Fisher (1989, Ch.2.4), assume perfect international capital mobility: countries can borrow or lend as much as they wish at a given world interest rate. Obviously a small developing country will benefit from opening up to the world capital market and its welfare will be unambiguously enhanced. Furthermore, now that borrowing and lending are feasible, capital will move quickly to equalize the domestic and the world interest rates, making a small open economy jump to its new steady state instantly in the absence of adjustment costs. The model's prediction follows: convergence is unconditional and instantaneous with zero adjustment costs, and rapid with positive adjustment costs.

Neither of these two polar cases accords well with the observed growth experience of small open developing countries. Recent empirical growth literature studies cross-country economic growth based on the closed-economy, augmented Solow model. Barro (1991), Levine and Renelt (1992), and Mankiw, Romer and Weil (1992), among others, seem to have confirmed the conditional convergence hypothesis in cross-country settings. However, a critical review of this literature reveals an empirical puzzle: African and Latin American countries grew systematically slower than the sample mean during the 1970s and 1980s. This puzzle is evidenced by the frequent presence of significant regional dummies, indicating "missing regularities" from the closed-economy model (Barro, 1991, p.435). Rejection of the open economy model with perfect capital mobility is even stronger: we simply do not witness either instantaneous, or at least rapid, convergence in cross-country growth. Not incidentally, the African and Latin American countries in the sample are the ones that borrowed heavily in the international loan markets during the 1970s and experienced a debt service crisis in the 1980s. Contrary to the prediction of the open economy growth model, borrowing did not seem to help these countries to grow.

The empirical puzzle remains since neither model captures accurately the external adjustment process that is crucial to the growth of a small borrowing economy. The closed economy model is inadequate because of its outright exclusion of external variables. The open economy model is misleading because it relies on strong informational and institutional assumptions, namely symmetric information, common knowledge, and enforceable contracts: assumptions that do not hold in the international loan markets.

This thesis reexamines the issue of cross-country growth under the assumption of open economies and imperfect capital mobility. The purpose is to capture the external adjustment process that is crucial to the growth of small open economies. Two alternative models are constructed, each adopting a different notion of imperfect capital mobility. In a model that is a variant of Barro et al. (1992), it is shown that the CCH can be extended to open economies if foreign borrowing can be used only to finance the accumulation of physical (but not human) capital. Furthermore, external variables such as debt and openness are expected to affect growth, either directly, or indirectly by affecting investment share.

The other model, an optimal growth model, is constructed to examine the growth of a small borrowing economy facing an exogenous credit ceiling in international loan markets (Isgut, 1993). In reality, international loan markets are characterized by asymmetric and incomplete information, and the contracts with sovereign borrowers are only partially enforceable due to the lack of collateral requirements and bankruptcy laws in international lending. Under these circumstances lenders may prefer to ration credit rather than raise interest rates to clear markets. Higher interest rates induce a given debtor to undertake riskier investment projects and create *moral hazard.* Higher interest rates also drive more risk averse borrowers out of the borrowing pool, thus causing *adverse selection.* A small borrowing economy therefore finds itself facing an imperfect international loan market in the sense that it can borrow at the going world interest rate only up to a specific credit ceiling, depending on its credit rating. It is constrained by a foreign borrowing ceiling (FBC). Similar problems are also present in domestic credit markets, which were studied by the pioneering working of Stiglitz and Weiss (1981). Isgut (1993) extends their work to model the decision problem of a small borrowing economy facing an FBC in international loan markets.

In Isgut's model, a small borrowing economy faces an exogenous credit constraint, B, beyond which no borrowing is possible. In other words, the supply curve of loans is an inverted L-shape. This formulation classifies a country into one of the three cases. If a country's optimal growth path is such that its foreign debt never reaches B--i.e. it is fortunate enough that it will never need to use all the credit lines available, as in the case of the U.S. or Canada--then the county's borrowing is never-constrained. In this case the country behaves *as if* it is facing perfect capital mobility: its paths of foreign debt and investment are smooth and consumption is constant throughout. If a country's initial debt value has already reached B and therefore no borrowing can occur during the planning horizon, then the country is ever-constrained. It is easy to see that these two extreme cases are identical to the standard neoclassical growth model of an open and closed economy. In the third case, it can be shown that under certain informational assumptions, a country may choose to borrow *optimally* up to its credit ceiling, B, and service the debt thereafter. This is the case of *optimal regime switching.* The steady-state and transitional dynamics are studied in each case, and it is shown that paths of output, investment, and foreign debt of a regime-switching economy exhibit kinks and different convergence properties from the closed economy--the medium run results in lower investment than would be the case without regime-switching. This result provides a plausible explanation for the aforementioned empirical puzzle that African and Latin American countries grew systematically slower than the sample mean during the past two decades.

These models pose serious challenges to the existing empirical growth literature. The conventional cross-country studies that assume either that external variables can be treated as omitted variables, or that observations of all countries are drawn from the same distribution, are misspecified. Model I suggests a natural way to incorporate variables such as debt and openness into econometric specifications. Model II implies that countries that are credit-constrained during the sample period should be classified separately from those that are not. This provides a theoretical underpinning for the earlier finding that convergence should occur within each growth "club" rather than between "clubs" (Baumol, 1986, Dowrick and Gemmell, 1991).

This thesis will be the first to test these open economy growth models empirically, and in doing so, it introduces open economy variables such as debt and trade into a structured open economy growth framework. In particular, it provides an explanation for the frequent presence of significant regional dummies in the literature.

The empirical part of the thesis includes several rounds of respecification. For 98 countries over the period from 1960 to 1985, data were drawn from the Penn World Table (Summers and Heston, 1992) and the World Debt Tables (The World Bank, 1993-1994 Version), as well as other sources. We first duplicate the well-known results of both Mankiw, Romer and Weil (1992), and Barro (1991). We then respecify the model (Model I) to incorporate external variables, yielding expected results regarding them. In light of diagnostic test results, that the investment variable is itself endogenous, we respecify the model as a simultaneous equation system, with one growth equation and one investment equation, and obtain consistent estimates with the three stage least square estimator (3SLS). Our results reconfirm the two-link chain identified by Levine and Renelt (1991): openness is positively correlated with the investment share and is therefore growth-promoting. Furthermore, to improve efficiency, we respecify the model to conduct a pooled cross-sectional and time-series analysis.

Finally, the determination of a country's credit ceiling is a empirical issue, and ultimately depends on the country's external debt serving capacity. To this end, more sophisticated econometric techniques are required. We construct a Logit model (Maddala, 1983; Greene, 1993) to determine the probability that a country will be credit-constrained. Such a model is capable to predict, based on certain characteristics of a country--its debt service ratio, its reserve-to-imports ratio, its debt to GDP ratio, average interest rates on its debt, real growth rate of its GDP, to name a few--whether the country should be classified as credit-rationed during the sample period.

A central objective has been to solve an empirical puzzle: African and Latin American countries grow systematically slower than the sample mean (Barro 1991, Levine and Renelt 1992, and Cohen 1990, 1993). Our theoretical and empirical findings attribute this to optimal regime switching when facing a foreign borrowing constraint. These countries converge to steady states that are different from those of the never-constrained economies.

This thesis contains eight chapters. Following a brief introduction in Chapter 1, Chapter 2 presents the augmented Solow model of growth employed in existing literature. Before presenting our two open economy models under imperfect capital mobility, we provide a background literature review in Chapter 3. In Chapter 4, we present the first model, a modified version of Barro et. al. (1992). In Chapter 5, the second model is constructed, in which a small open economy faces a possible credit ceiling, drawing upon Blanchard and Fisher (1989) and Isgut (1993). Empirical implications for cross-country growth are studied in each case.
Chapter 6, presents empirical estimates for various closed and open economy specifications as suggested by the models. For the purpose of predicting the probability of a debtor's being credit constrained, Chapter 7 develops and estimates a Logit model. Finally, Chapter 8 presents summary and conclusions.

Chapter 2 A Closed economy Model of Growth--The Augmented Solow Model

In this chapter, we outline the closed economy neoclassical growth model, a Solow model augmented to include accumulations of human capital (Mankiw, Romer, and Weil, 1992). This model was used in a successful defense of the Solow model by the above authors against the attacks from the endogenous growth school, and has since become the accepted departure point for most recent empirical growth literature. And as such, it serves best as a reference point for extensions and departures.

For the moment, assume the economy is closed. No international borrowing or migration is possible. Output is produced with three inputs: physical capital, human capital, and raw labor. we also assume that output can either be converted to investment or consumption goods, and vice versa, at no extra costs and that the one-sector production function is Cobb-Douglas:

(2.1) $$Y_t = K_t^{\alpha} H_t^{\beta} (A_t L_t)^{1-\alpha-\beta} \qquad \alpha > 0, \beta > 0, \ and \quad \alpha + \beta < 1$$

As usual, Y is output, K physical capital, H human capital, L raw labor, and A the labor-augmenting level of prevailing technology. A and L are assumed to grow exogenously at rate g and n, respectively, e.g., $A_t = A_0 e^{gt}$, $L_t = L_0 e^{nt}$. In production function (2.1), it is assumed that $\alpha + \beta < 1$, so that there are constant returns to reproducible factors jointly, and decreasing returns to each factor separately.

Defining Y, K, and H in effective labor units--$y_t = Y_t / A_t L_t$, $k_t = K_t / A_t L_t$, and $h_t = H_t / A_t L_t$ -- the production function is then given in intensive form by

(2.2) $$y_t = k_t^{\alpha} h_t^{\beta}$$

If we further assume that a fraction of income, s_k, will be saved and invested in physical capital, and s_h in human capital, then the evolution of the economy is governed by

(2.3a) $$\dot{k}_t = s_k y_t - (n + g + \delta)k_t$$

(2.3b) $$\dot{h}_t = s_h y_t - (n + g + \delta)h_t$$

where δ is the rate of depreciation, assumed common to both human and physical capital.

2.1 The Steady State

The steady state is defined as the long run equilibrium when $\dot{k} = 0$ and $\dot{h} = 0$ hold simultaneously. Equivalently, when measured in effective labor units, the levels of physical and human capital are constant in steady state, so is the level of output. These constant steady state levels (denoted by asterisks) are implied by equations (2.3a) and (2.3b):

(2.4a) $$k^* = \left(\frac{s_k^{1-\beta} s_h^{\beta}}{n + g + \delta} \right)^{\frac{1}{1-\alpha-\beta}}$$

(2.4b) $$h^* = \left(\frac{s_k^{\alpha} s_h^{1-\alpha}}{n + g + \delta} \right)^{\frac{1}{1-\alpha-\beta}}$$

(2.4c) $$\ln y^* = -\left(\frac{\alpha + \beta}{1 - \alpha - \beta} \right) \ln(n + g + \delta) + \left(\frac{\alpha}{1 - \alpha - \beta} \right) \ln s_k + \left(\frac{\beta}{1 - \alpha - \beta} \right) \ln s_h$$

Equation (2.4c) expresses the constant output level per effective labor in its logarithmic form, which is obtained by substituting steady state levels of capital (2.4a) and human capital (2.4b) into the production function (2.2), and then taking logs of both sides of the resulting equation.

While the steady state growth rate of output in units of effective labor is zero, (since its level is constant), the per capita output grows at the rate of productivity growth, g. This result can be obtained directly from the definition of output per effective labor, $y_t = Y_t / A_t L_t$, which implies the following relationship:

$$(2.5) \quad \begin{aligned} \ln y_t &= \ln(Y_t / L_t) - \ln A_t \\ &= \ln(Y_t / L_t) - \ln A_0 - gt \end{aligned}$$

To get the relationship between the two growth rates in different labor units, we take time derivatives of both side of the equation (2.5), which yields:

$$(2.6) \quad \frac{d \ln y_t}{dt} = \frac{d \ln(Y_t / L_t)}{dt} - g \quad \text{or} \quad g_y = g_{Y/L} - g$$

2.2 Transitory Dynamics Towards the Steady State

Empirical research on economic growth, cross-country and over time, is based on the theoretical results of convergence, i.e., on the transitory dynamics toward steady state. The study of the dynamics has the advantage in that we do not have to restrict the economy to be in its steady state continuously. All that is required is the assumption that the economy is sufficiently close to its steady state that a linearization is appropriate.

In the case of the augmented Solow model, its transitory dynamics generates the hypothesis of "conditional convergence" referred to in the cross-country growth literature. This hypothesis maintains that a country's per capita income should converge -- a poor country with lower initial income level should grow faster than a rich country -- only if one controls for the taste (saving rates) and technology parameters that determine the steady state. The quantitative convergence implication of the model was first derived by Barro and Sala-i-Martin (1992). Let y^* be the steady state income level per effective unit of labor as given by equation (2.4c), and let y_t be the actual output level at time t, by approximating the log-linear system around the steady state,[1] the instantaneous growth rate of y_t at time t can be written as

[1] This linear approximation around the steady state is derived in Appendix A.

(2.7) $$\frac{d\ln y_t}{dt} = \lambda(\ln y^* - \ln y_t)$$

where λ is the speed of convergence such that

(2.8) $$\lambda = (1-\alpha-\beta)(n+g+\delta).$$

Notice that λ is a decreasing function of the broad capital share, $\alpha + \beta$, and equals zero when $\alpha + \beta = 1$.[2] Therefore, convergence depends crucially on the assumption of diminishing returns to reproducible factors, $\alpha + \beta < 1$.

Equation (2.7) is a first-order linear differential equation of a special type.[3] Solving for $\ln y_t$ will give us the time path of income (in its logarithmic form) toward the steady state. Given initial conditions that at some time *t=0*, initial income level is y_0, the solution to this differential equation is

$$\ln y_t = (\ln y_0 - \frac{\lambda \ln y^*}{\lambda})e^{-\lambda t} + \frac{\lambda \ln y^*}{\lambda}$$

which can be simplified to obtain

(2.9) $$\ln y_t = (1-e^{-\lambda t})\ln y^* + e^{-\lambda t}\ln y_0$$

Equation (2.9) characterizes the entire time path of the income level, as the economy moves toward the ultimate steady state from its initial income level y_0 at *t=0*.

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[2] In that case, the model becomes an endogenous growth model. No convergence occurs.

[3] The general form of this special type (with constant coefficients) of differential equation is $\frac{dz_t}{dt} + az_t = b$.

The definite solution to it is $z_t = (z_0 - \frac{b}{a})e^{-at} + \frac{b}{a}$, provided a≠0. We can ascertain equation (7) belongs to this family of equations by setting $z = \ln y_t$, $a = \lambda$, *and* $b = \lambda \ln y^*$.

As Mankiw et al. (1992) point out, if one employs figures that seem approximately valid for the U.S. economy, n=0.01, g=0.02, δ=0.03, α=0.33 and β=0.33, the rate of convergence is λ=0.02 per year, which means the economy will move halfway to the steady state in about 35 years.[4] [5] Another set of plausible parameter values was employed by Barro et at. (1992) with slightly higher human capital share and depreciation rate, so again n=0.01, g=0.02, but δ=0.05, α =0.3 and β=0.5. In that case convergence is slower at a rate of λ=0.014 per year, so that it will take the economy a longer time (about 49 years instead of 35 years) to move halfway to the steady state.

2.3 Empirical Implications for Cross-Country Growth

Our purpose is to derive the econometric specification for the determinants of growth *rate* on the transitory path, outside of the steady state. In order to do so, we concentrate on the change of per capita income from time *0* to *t* by subtracting $\ln y_0$ from both sides of the above solution to get

$$\ln y_t - \ln y_0 = (1-e^{-\lambda t})(\ln y^* - \ln y_0) \tag{2.10}$$

Bearing in mind that y is defined in terms of the effective unit of labor, i.e., $y_t = \frac{Y_t}{A_t L_t}$, and therefore

$$\ln\frac{Y_t}{A_t L_t} - \ln\frac{Y_0}{A_0 L_0} = (1-e^{-\lambda t})\ln y^* - (1-e^{-\lambda t})\ln\frac{Y_0}{A_0 L_0}, \tag{2.10'}$$

we can transform this into per capita terms, using the relationship $A_t = A_0 e^{gt}$, where g is the exogenous growth rate of the labor augmented technology.

$$\begin{aligned} left &= (\ln\frac{Y_t}{L_t} - \ln\frac{Y_0}{L_0}) - (\ln A_t - \ln A_0) \\ &= (\ln\frac{Y_t}{L_t} - \ln\frac{Y_0}{L_0}) - gt \end{aligned}$$

[4] To calculate the half-time, simply set *y=0.5y** in $y = y^*(1-e^{-\lambda t})$ and solve for time, t.

[5] In the original Solow model that does not include human capital (β=0), the predicted convergence occurs much faster, with λ=0.04 and the half-time about 17 years.

Substituting this result and steady state level of income $\ln y^*$ (from equation (4c)) back to equation (2.10') and rearranging, we get:

$$
\begin{aligned}
\ln\frac{Y_t}{L_t}-\ln\frac{Y_0}{L_0} &= -(1-e^{-\lambda t})\left(\frac{\alpha+\beta}{1-\alpha-\beta}\right)\ln(n+g+\delta) \\
&+(1-e^{-\lambda t})\left(\frac{\alpha}{1-\alpha-\beta}\right)\ln s_k+(1-e^{-\lambda t})\left(\frac{\beta}{1-\alpha-\beta}\right)\ln s_h \\
&-(1-e^{-\lambda t})\ln\frac{Y_0}{L_0}+gt+(1-e^{-\lambda t})\ln A_0
\end{aligned}
\tag{2.11}
$$

Hence, equation (2.11) suggests a specification of income growth as a function of determinants of the ultimate steady state and the initial level of income. It is the theoretical foundation of the cross-country growth literature. It should be emphasized again that this growth rate under study applies to the transitory paths outside the steady state, thus does not require restrictive assumptions that the economy is in steady state continuously, where the growth rate of y is simply g.

Given that the speed of convergence is positive, i.e. $\lambda > 0$, the expected signs of the coefficients is equation (2.11) can be determined. The first term indicates that for a given set of α, β, δ, and g, per capita income growth is negatively related to population growth. The second term captures the role played by the capital investment in the process of economic growth. The more a country chooses to save and invest, the faster its economy grows. A similar analysis holds for the third term which applies to saving and investment in accumulating human capital. It is the fourth term that indicates the "conditional convergence" hypothesis: ceteris paribus, a country grows faster per capita, if its initial income level is further below its steady state position (Mankiw et al., 1992, Barro, 1991, Levine and Renelt, 1992, and Barro and Lee, 1993). The next term, gt, simply reflects the time specific effect on growth as technology keeps on growing at a rate g. The last term containing $\ln A_0$, represents all the unobserved (and unaccounted for) elements that determine the efficiency with which the productive factors and the available technology are used to create wealth.

One attempt to identify the unaccounted factors in $\ln A_0$ is made by Barro (1991). Realizing that the country-specific effect may be captured by continent-specific effects, Barro constructed two regional dummy variables, an African dummy and a Latin American dummy. The significantly negative estimated coefficients of these dummies, despite efforts to account for them by using political variables, lead him to conclude that "some regularities are missing from the (closed economy) model" (Barro, 1991, p.435). In subsequent studies these dummy variables emerged time and again, along with a third, significantly positive regional dummy, East Asia. (See, for example, Barro and Lee, 1993). Empirical investigations that concentrate on these regional growth experiences do exist. However, these come from both the debt literature and the export-led growth literature, and for the most part, have been overlooked by the cross-country growth literature.

The debt crisis of the 1980s has generated a large body of research on debt-related issues. The generally received views by academics and the international community is that excessive foreign debt creates a disincentive to invest, thus hurting economic growth (Krugman 1988, Cohen 1991). Not incidentally, the African and Latin American countries in the sample are the ones that borrowed heavily in the international loan markets during the 1970s and experienced a debt service crisis in the 1980s. Cohen (1991) documented that during 1980-87, while the debt service ratio (defined as the ratio of debt service to export earnings) climbed from 9.7% to 19.6% for Sub-Saharan Africa and from 37.1% to 43.7% for Latin America, investment plummeted 8.3 percent and 4.5 percent respectively, contributing to slow growth records of 0.4 and 1.4 percent, compared to the sample mean growth of 4.0 percent for the group of all LDCs. But no formal investigation in a cross-country setting has been conducted within the context of structural growth models, because the closed economy of the augmented-Solow model excludes external variables outright, debt variables or otherwise.

On the merrier side, it has long been recognized by the export-led literature that controlling variables such as trade shares have important bearing on convergence, (For a recent treatment, see Helliwell, 1992), and this may be the key to account for the successful East Asian growth experience. Abundant evidence from these studies is available, and has been summarized, most recently, by a comprehensive policy research project undertaken by the World Bank (World Bank, 1993). But again, the fruits of these studies have not been systematically incorporated into the cross-country growth literature, since the maintained assumption of the closed economy renders it difficult to justify the inclusion of external variables, such as foreign debt and trade shares, as explanatory variables. In some cases, trade variables are employed on *ad hoc* bases. On the one hand, it is difficult to evaluate these studies without a clearly specified structural model. On the other hand, Levine and Renelt (1992) does identify a strong and robust empirical two-link chain between openness and investment and between investment and growth performance, after surveying 41 cross-country growth studies and performing sensitivity analysis on an extended group of explanatory variables.

Both arguments point to the inadequacy of the closed economy augmented Solow model as applied to the cross-country growth literature. Its implicit assumption of a closed economy, which might have been a reasonable assumption when the original Solow model was developed during the 1950s and even in 1960s, excludes the external adjustment process that is crucial to the growth of a small open economy in the 1970s and 1980s, growth that has occurred in a very different international economic environment.

In this new, global economic environment the roles played by a country's external balance and its export-import sector in affecting a country's growth become overwhelmingly important and are no longer negligible. These factors should be modeled explicitly in cross-country growth comparisons. Ideally, such models should capture the following two established empirical regularities, running in opposite directions. On the one hand, the share of the traded-goods sector, defined and measured broadly as an indication of an economy's openness, and contributes to economic growth by improving the efficiency of production and investment. This is achieved through various channels, from technology transfer to intersectoral spillovers. On the other hand, excessive foreign borrowing, in the face of international shocks of high interest rates and low commodity prices, subsequent debt service crisis and binding credit constraints, could seriously undermine a country's growth record by severely distorting domestic investment incentives.

These arguments call for extensions to an open economy growth model. However, as we will soon review in detail in Chapter 3, an open economy growth model constructed under the conventional assumption of perfect capital mobility fails to produce economically meaningful transitory dynamics to guide empirical studies. To see why this is so intuitively, suppose a small open economy is now facing a constant world interest rate, r^W. Capital can flow but labor migration is still ruled out. Now that borrowing and lending are feasible, capital will move to equalize the domestic interest rate and the world interest rate, and domestic interest rate r will be pegged at a constant $r=r^W$. Consequently, the implied values of h and k, and hence y, will also be constant. That is, the model predicts an instantaneous jump of the small open economy to its new steady state levels of human capital, physical capital, and output, and to remain there forever after. The corresponding rate of convergence is infinity, $\lambda \rightarrow \infty$, a result that conflicts sharply with the observed growth experience: we simply do not witness this type of instantaneous convergence. To be reconciled with the observed patterns of growth, this and other undesirable properties of the open economy version of the model would have to be amended.[6] A more comprehensive critique will be presented in the next chapter.

Thus a search for alternative assumptions about international capital mobility is in order. And different forms of imperfect capital mobility produce different yet complementary results. To see clearly why this is so, we now turn to a brief literature review of open economy growth models that introduce the debt and trade variables into the modeling. Following the convention of the theoretical growth literature post-Solow, the review is carried out in an optimal growth framework, where paths of consumption, investment, debt, and growth are derived from a maximization framework.

[6] See the surveys by Eaton (1989, 1992).

Chapter 3 A Brief Literature Review On Dynamic Models of Growth and Indebtedness

For our purposes, models which study the relationship between a small borrowing country's short-run and long-run growth rates and its indebtedness can be divided into two large groups. These two groups, along with their characteristics and major references, are summarized in Table 3.1. Models in Group A are constructed under the assumption of perfect international capital mobility, and rely on the following assumptions with respect to international loan markets:

A1. Perfect competition among creditors.
A2. Complete information: lenders know the production possibility curve of the borrowing country.
A3. Enforceable contracts.
A4. Common knowledge with respect to assumptions A2 and A3 by both creditors and the borrowing country.

By contrast, models in Group B relax the assumption of perfect capital mobility, either because one of the above assumptions A1-A4 is violated (Isgut 1993), or because some restrictions on accumulating reproducible factors such as human capital are introduced (as in Barro, Mankiw and Sala-i-Martin, 1992). Some of these models are summarized in Table 1. It should be mentioned that there exists a large body of dynamic models in the debt literature, that investigate issues associated with possibility and consequences of defaults.[7] Since the present thesis is concerned with the implication of two *ex ante* forms of a credit constraint for a small borrowing economy and its empirical implication for cross-country growth, these papers are, while important, beyond our limited scope. We will simply refer interested readers to the references.

Section 3.1 of this review will start from a benchmark model from Group A (Blanchard and Fisher, 1989, Ch.2.4), outlining the major predictions of the model with respect to its steady-

[7] For example, both Cohen and Sachs (1986) and Cohen (1991) impose a penalty constraint on a borrowing country with an uncertain future outputs, therefore a probability of repudiation. Eaton and Gersovitz (1986) and Eaton (1993) impose an enforcement constraint. Kletzer (1984) studies the lender's problem caused by asymmetric knowledge between lenders and debtors about the latter's uncertain future income. Hellwig (1977) shows that under these circumstances lending may break down due to lender's inability to precommit himself to a credit ceiling. Finally, for an up to date review of the default literature, see Bowe and Dean (1994).

state output growth and the paths of consumption, investment and saving, as well as the level of debt accumulation and the balance of payments. Section 3.2 then proceeds to review and compare the models in Group B when capital mobility is limited in some sense, focusing on a modified Isgut model (Isgut, 1993). To keep these optimal growth models and their conclusions tractable, throughout this section we abstract from modeling human capital since both forms of the borrowing constraint are expressed in terms of physical capital alone. The result from these models on the transitory dynamics can be easily expanded to accommodate human capital accumulation. One way to achieve this is to combine the accumulation equations for human capital, physical capital and debt together, as did in Barro, Mankiw and Sala-i-Martin (1992). A simplified version of that model is presented in Chapter 4 when it is necessary to model human capital explicitly.

	Group A	**Group B**	
Characteristics/ /Model	Capital Perfectly Mobile $r = r^W$	Capital Partially Mobile (I) $b_t < B$ (exogenous ceiling)	Capital Partially Mobile (II) $b_t < k_t$ (physical capital)
Survey	Eaton (1989)	Eaton(1993)	
Benchmark Model, One-Sector	Blanchard and Fischer (1989, Ch. 2.4)	Isgut (1993)	Barro, Mankiw and Sala-i-Martin (1992)
Time Variant Discount Factor, One-Sector	Uzawa (1968)		
Borrow for Investment, Two-Sector	Engel and Kletzer (1986, 1989)		

Table 1 Dynamic Models of Growth and Indebtedness

3.1 Dynamic Models of Growth and Debt with Perfect Capital Mobility

In this section, we will review dynamic models of optimal growth and debt constructed under the assumption of perfect capital mobility. For this assumption to be valid, all the strong informational and institutional assumptions A1 to A4 have to hold. The benchmark model in this group uses infinite horizon utility maximization and a one-sector neoclassical production function (Solow, 1956). A limitation of these kinds of models is their frequent failure to produce economically meaningful steady states and their lack of transitory dynamics.

Let us consider the one-sector prototype model of Blanchard and Fisher (1989, Ch.2.4).[8] The agent in this model is an infinitely lived central planner whose problem is to maximize the present discounted value of his utility from consumption, subject to a *dynamic budget constraint* and *the transversality condition*:[9]

(3.1a) $$Max\ U_0 = \int_0^\infty u(c_t)\, e^{-(\theta - n)t}\, dt$$

subject to

(3.1b) $$c_t = y_t + m_t - i_t$$

(3.1c) $$\dot{b}_t = (\theta - n - g)b_t + m_t$$

(3.1d) $$\dot{k}_t = i_t - (n + g + \delta)k_t$$

(3.1e) $$\lim_{t \to \infty} b_t\, e^{-(\theta - n - g)t} \leq 0$$

where $\dot{b}_t \equiv \frac{db_t}{dt}$ *and* $\dot{k}_t \equiv \frac{dk_t}{dt}$

$c_t, k_t \geq 0 \quad \forall t,$ $\qquad k_0, b_0$ *given*

Variables, denominated in units of effective labor, are defined as follows:

[8] For the purposes of studying the model's steady-state growth and convergence toward steady-state, two minor modifications of Blanchard and Fischer's model are made in the present model. In their model the population is assumed to be constant and there are positive adjustment costs associated with investment. Here, to start with I assume population grows at a rate n and there is no adjustment cost. The implication of positive adjustment costs will be dealt with later.

[9] Barro, Mankiw and Sala-i-Martin (1993) give the solution for the decentralized equilibrium. There is an equivalence between the prototype command optimum and decentralized equilibrium approach. For a proof of this proposition, see Blanchard and Fisher (1989, Ch.2, Appendix C).

y_t : output
k_t : physical capital
c_t : consumption
i_t : investment
b_t : level of debt.
m_t : net imports, or trade deficit

Parameters are defined as:

n : rate of population growth
g : growth rate of labor-augmenting technology
δ : rate of depreciation of capital
θ : subjective rate of time preference (or the discount factor), $0 < \theta < 1$.
r : world interest rate, for simplicity is assumed to be equal to the effective discount factor; i.e. $r = \theta = n + g$.[10, 11]

Equation (3.1a) is the objective function of the borrowing country, whose temporal utility function, $u(c_t)$ in each period t is strictly increasing and strictly concave.[12,13] Equation (3.1b) is the temporal budget constraint which specifies consumption in each period as total resources available in that period, output and net imports, minus gross investment undertaken in the same period. Equation (3.1c) states that the change in foreign debt is the current account deficit which is in turn equal to the sum of interest payments and net imports, or, implicitly, the difference between investment and saving. Together, (3.1b) and (3.1c) imply a dynamic budget constraint which specifies that the debt level grows in each period by exactly the difference between the sum of domestic absorption and foreign interest payments, and the output available. Equation (3.1d) establishes that capital accumulated in each period equals gross investment net of effective depreciation.

Last but not least, inequality (3.1e) is *the transversality condition* that has to be imposed on the borrowing country under the assumption of a perfect international loan market. If the international loan market is perfect and lenders are rational, then eventually there has to be a point in time when debtors start to make net resource transfers to creditors. For that to occur, the borrowing country is restricted from choosing a debt path that is so high that the present

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[10] $r > n$ is typically imposed since the condition $r < n$ implies a case where a country has infinite wealth, which is not economically interesting.
[11] The more general case where international interest rate $r \neq \theta$ is discussed below. See also Eaton (1993).
[12] The usual Inada conditions apply: $u'(0) = \infty$ and $u'(\infty) = 0$.
[13] This utility function belongs to a more general class: utility functions that are additively separable across time.

discounted value of debt in the infinite future is positive. This is the condition that embeds the notion of perfect capital mobility and thus sets apart a Group A model from a Group B model. It relies on the strong informational and institutional assumptions (A1 to A4). Technically, this condition requires debt to increase asymptotically more slowly than the level of the effective rate of interest. That is, it prevents higher and higher levels of borrowing from being used to meet interest payments on the existing debt.[14] Notice that this condition does not rule out the case when b_t remains positive for all periods, that is, when the country remains a net debtor forever. What it does rule out is the case when debt grows too fast, so fast that, on average, it outgrows the level of the interest rate, a situation that is not consistent with rational behavior on the part of lenders.

In order to analyze growth, the model must specify a production function.[15] As in other optimal growth models, we assume a Cobb-Douglas form with constant returns to scale (Solow, 1956). That is (abstracting from human capital)

$$(3.2a) \qquad Y_t = K_t^{\alpha} (A_t L_t)^{1-\alpha}, \qquad 0 < \alpha < 1$$

or in "intensive form" which defines output and capital in effective labor units:

$$(3.2b) \qquad y_t = k_t^{\alpha}$$

where $y_t = Y_t / A_t L_t$, $k_t = K_t / A_t L_t$, and A is the level of labor-augmenting technology. L and technology A are assumed to grow exogenously at rates n and g, respectively. Again, one-sector production technology is implicitly assumed here: output can be used as either investment or consumption, and conversion between the two uses of output is costless.[16]

[14] This condition is called No-Ponzi-Game condition by Blanchard and Fisher (1989).
[15] Earlier Harrod-Domar model (Harrod 1939 and Domar 1946) and two-gaps models (Mckinnon 1964) posit the more restrictive Leontief technology.
[16] In other words, this is the "schmoo good" so named in the literature. See for example, Engel and Kletzer (1986, endnote 1.)

We define a steady-state as the long-run intertemporal equilibrium when $\dot{b}_t = 0$ and $\dot{k}_t = 0$ hold simultaneously. Also, we use asterisks to denote steady state values. The above model has three fundamental implications with regard to steady state output growth, and the transitory paths of consumption, investment, debt and the current account.

First, the steady state growth rate of the variables in units of effective labor is zero, the per capita variables grow at the rate of productivity growth g, and the output level variables accordingly grow at a rate equal to the rate of population growth plus the rate of productivity growth, $n+g$.[17] Hence foreign borrowing does not contribute to the long run (e.g. steady state) growth of the borrowing country. In the steady state the current account must be balanced, since $\dot{b}_t = 0$. The trade surplus is offset by interest payments on the debt. Therefore the steady state level of debt b^* is positive. Recall that this is feasible under the transversality condition (3.1d).

Secondly, in the absence of adjustment costs for investment, this model has no transitional dynamics. Capital will move quickly to equalize the marginal product of domestic capital and the world interest rate $f'(k_t^*) = r$. Thus the steady state level of capital stock k_t^* and output y_t^* are implicitly determined as constants.[18] That is, the model predicts an instantaneous jump of the small open economy to its new steady state levels of capital and output, where it remains forever after. This quantitative convergence implication of the model is derived by Barro and Sala-i-Martin (1992): the rate of convergence is infinity, a result that conflicts sharply with empirical evidence. We could eliminate the infinite speeds of convergence by introducing adjustment costs for capital. However, modifications along this line (e.g. in Blanchard and Fischer, 1989) do not eliminate the counterfactual prediction that the convergence rate would be rapid in an open economy with perfect capital mobility. In any case, if factor supplies are exogenous and returns to scale are constant, foreign borrowing can affect growth only in the very short run, as a country borrows to bring its marginal product of capital into the line with the world interest rate. In other words, borrowing for investment in this model should occur almost all at once, at the beginning of

[17] Barro et.al (1992).
[18] It is more straitforward to show this in a decentralized equilibrium model, such as in Barro, Mankiw and Sala-i-Martin (1992).

the planning horizon, with an extremely high rate of investment, a rate that is independent of saving and consumption, as well as of the debt level.

The third implication of the model is related to consumption. Consumption is constant on an optimal path, given the assumption that the international interest rate equals the effective discount rate. International borrowing and lending facilitate consumption smoothing so that for a given present discounted value of output the timing of consumption is completely separated from that of production. One feasible adjustment process is depicted in figure 1. Suppose that net output, $f(k_t) - i$, increases over time. It starts out below and eventually exceeds consumption. The initial excess of consumption over net output is achieved by foreign borrowing, or by running a current account deficit. Debt accumulates during this phase when $t<t_1$. Eventually, net output rises sufficiently so that the trade balance shows a surplus. In the steady state, this trade surplus is measured by AB in each period, and it offsets exactly the perpetual interest payments, i.e. $rb^*=AB$. The constant consumption must be at the level such that the present discount value of net output minus consumption is zero, or equivalently that present discounted value of current and future trade surpluses is zero. In Figure 1, that means the discounted values of the two hatched areas must be equal with opposite signs.

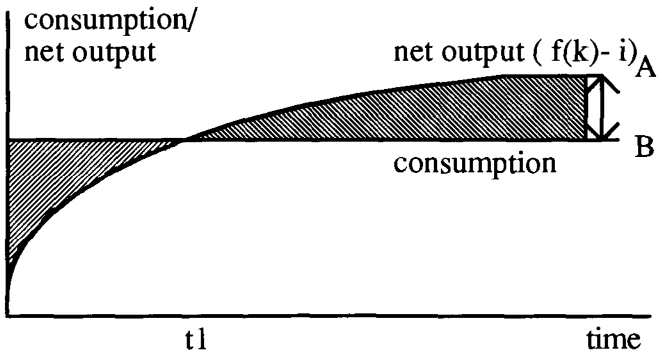

Figure 1. Consumption, net output, trade and current accounts

Several variants of the above model exist in the literature, generating additional results. However, in most cases the main results remain intact. In Eaton (1993), a case is studied where output per period, y_t, is given exogenously. Little is affected, however, as long as the production technology exhibits constant returns to scale and other factors of endowment in the previous model are exogenous.[19]

A special case worth mentioning is when the production technology exhibits constant returns to the reproducible factor, capital (i. e. when $\alpha = 1$ in equation (2)). In that case, the model becomes an "endogenous growth" model; in the sense that the growth rate in the long run is no longer exogenously determined by the technological parameters; instead, the long run growth rate is endogenously determined by the investment rate and the world interest rate. There is no steady state, and therefore no convergence occurs even in the long run.[20]

Eaton (1993) also relaxes the simplifying assumption that the borrowing country's effective discount rate equals the world interest rate. He finds that consumption is not constant if $r \neq \theta + n$. Instead consumption rises or falls over time depending on whether $r(\theta + n)$ is larger or smaller than one, or whether the world interest rate is higher or lower than the country's effective discount rate. Eaton (1989) points out the unappealing steady state properties of these two cases. If $r > \theta + n$, there is no steady state; consumption and therefore national wealth is forever increasing. If $r < \theta + n$, consumption falls toward zero.

The Group A models reviewed so far suffer from two major deficiencies. As outlined in the previous paragraph, models with constant discount rates in most cases fail to generate economically interesting and meaningful steady states for a small open economy under perfect capital mobility. This can be remedied by endogenizing the discount rate, θ. For example, Uzawa (1968) provides a specification of preferences in which the discount rate depends on previous consumption. The other deficiency is that in an one-sector model the motive of borrowing for consumption smoothing can not be distinguished from that of borrowing for investment. For that purpose, a two-sector specification is necessary.

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[19] Related models in which the endowment fluctuates stochastically are beyond the scope of this thesis. Following Eaton (1993), I refer interested readers to Crossman and van Huyck (1988).
[20] See, for example, Lucas (1988) and Cohen (1991) for two quite different endogenous growth models.

In two papers Engel and Kletzer (1986, 1989) modify the analysis of optimal borrowing models to overcome these two deficiencies. In their two-sector model, Uzawa's specification of a variable discount factor is adopted and an assumption is made that borrowing can only occur for investment purposes. Their model is capable of generating a much richer dynamic structure, one that provides an optimizing explanation of stages in the balance of payments. A capital scarce country will initially borrow from abroad to finance profitable investment opportunities at home. When the productivity of domestic capital at the margin has been reduced to equality with the return from traded assets, the incentive to borrow to increase the domestic capital stock is eliminated. At that point the country may have a high enough saving level to allow it eventually to pay off its debts and increase its wealth. Gradually it could become a net creditor with high level of per capita consumption. Notice this is a very different prediction from that of our prototype model in which debt remains positive even in the steady state.

However, not all is well with the variable discount factor approach. Despite its promise to overcome the technical deficiencies, this specification generates some counterintuitive implications (Eaton, 1989). Furthermore, empirical tests support no systematic relationship between per capita income and the balance of payment position (Halevi, 1971).

3.2 Dynamic Models of Growth and Debt with Imperfect Capital Mobility

Given that behavior of the international credit market is not well represented in the benchmark model, modifying time-preferences while retaining the other features of the model seems to be misdirected. Another arm of the literature questions the assumption of perfect capital mobility. It is questionable how mobile capital is, even among industrial countries. Evidence shows (Gersovitz, 1985) that the consumption-smoothing model, like our benchmark model, describes borrowing by developing countries very poorly. The group B models that will be reviewed in this subsection feature the theoretical developments in the optimal growth literature on this front.

Recall that perfect capital mobility is a strong assumption which in turn rests on the assumptions A1-A4 posited earlier, namely perfectly competitive lending, complete information, perfectly enforceable contracts, and symmetric knowledge between lenders and borrowers alike. With the exception of perfect competition, each of the above assumptions has been challenged in the literature, and rightly so. For analysis of loan markets under imperfect information see Stiglitz and Weiss (1981) and Hellwig (1977), loan markets under asymmetric information see Kletzer (1984), loan markets with potential repudiation see Eaton and Gersovitz (1981) and Cohen and Sachs (1986). This literature focuses on the strategic interaction between a borrower and its creditors. The central problem is "how international lending takes place under conditions of imperfect (and asymmetric) information and the lack of enforceability that characterizes sovereign loan contracts. How do lenders deal with problems of moral hazard, adverse selection or the possibility of the outright repudiation?" (Isgut, 1993). While the causes of the problems vary, the consensual answer to this question is that they will result in credit rationing. In other words, one can justify the existence of credit ceilings when assumptions A1-A4, or any combinations of them, are violated. This amounts to replacing *the transversality condition* (1d) by the *foreign borrowing constraint* or FBC. Analytically this means to replace

(3.1e) $$\lim_{t \to \infty} b_t \, e^{-(\theta-n-g)t} \leq 0$$

with the following FBC condition:

(3.1e') $$b_t - B \leq 0$$

The critical question then becomes: How is B determined? The existing literature offers various answers.

In an attempt to remedy the implausible property of instantaneous convergence predicted by the benchmark model, Barro, Mankiw, and Sala-i-Martin (1992) assume that the credit ceiling is identical to the borrowing country's existing stock of physical capital, so that equation (1e) becomes

(3.1e") $$b_t - k_t \leq 0,$$

The reason is that only physical (but not human) capital can serve as collateral when borrowing internationally. Their main result is that if capital mobility is imperfect in this particular sense as represented by equation (1e"), then the credit constrained open economy behaves in a way similar to that of a closed economy: it converges only slowly. This model offers a justification for including external variables in empirical cross-country growth studies. A simplified version of this model will be studied in Chapter 4. Furthermore, in Chapter 6 and 7, this thesis will be the first one to test the empirical implications of BMS model, using cross country regressions.

There are at least three alternative ways to characterize imperfect capital mobility. In models with one capital good, one can assume that only a fraction of capital v<1 serves as collateral (Cohen and Sachs, 1984). In models with more than one capital good with trade, one can assume that only tradable goods can serve as collateral. If foreign loans are made directly to the domestic government, then the collateral involves the security put up by the government, which may be substantially less than physical capital.

In practice, credit ceilings depend on many more factors other than the borrowing country's capital or output of any measures, including factors that are beyond the strategic interaction of an individual borrower and its lender, and factors that are not necessarily related to its solvency. Rather, historical episodes of international financial crises generally affect the creditworthiness of borrowers as a group. So any individual borrower has to estimate its own credit ceiling using all information about its own current and future output, as well as the past shocks to, and the current state of the international loan market. When a borrowing country makes a decision under this circumstance, the perceived credit ceiling is a given. Chapter 5 of this thesis, like Isgut (1993), is concerned with the implications of this market environment for capital accumulation and the growth of a borrowing country, and its empirical implications for cross-country growth. The main questions are: (1) How can a borrower faced with a possibly binding credit constraint choose its optimal consumption and investment paths to avoid time inconsistency? (2) What are the empirical and policy implications of such a model? In other words, can this model, when applied empirically, provide a plausible explanation for the empirical puzzle that African and Latin American countries have been growing systematically slower than the sample mean?

Chapter 4 An Open Economy Model with Imperfect Capital Mobility

As discussed in Chapter 3, the dynamic deficiency of the open economy model under perfect capital mobility can be remedied by introducing the notion of imperfect capital mobility. Two of such models will be studied in this thesis, each employing a particular notion of imperfect capital mobility. In this chapter, we present a variant of the model developed by Barro, Mankiw and Sala-i-Martin (1992) (henceforth BMS model), which has never been tested empirically. An alternative model will be studied in Chapter 5. Our purpose here is to extend the empirical framework for cross-country growth, originally derived from the closed economy, augmented Solow model in Chapter 2, to an open economy setting. To keep the exposition style in tone with the augmented Solow model of Mankiw, Romer and Weil (1992), which provides the basic empirical structure for cross-country growth, we have simplified the BMS model and focused on the transitory dynamics of their formulation. Specifically, in the original BMS model, the gross saving rate which includes savings in both physical and human capital, i.e. $s = s_k + s_h$, was derived from a maximization framework. But the transitory dynamics and speed of convergence of their model were derived after imposing the assumption of constant saving rates. Therefore, since we are interested only in the transitory dynamics of the BMS model, we have assumed saving rates s_k and s_h to be constants throughout, and have not modeled other factors (e.g. taxes) that help to determine the saving rates. As a result, our formulation is capable of generating the same convergence results as those in the BMS model, yet its simplicity allows one to test the BMS model and obtain results for convergence directly comparable to the MRW results. The issue of the endogeneity of the saving rate and simultaneity of income growth and saving will be touched upon later in this chapter when empirical implications of the BMS model are drawn, and will be further dealt with as specification issues in Chapter 6 and 7.

4.1 The Model

The key assumption in this model is that the country can borrow to finance the accumulation of physical capital k, but not the accumulation of human capital, h. In other words, k can serve as collateral in the international capital market but h can not. The open economy has the same production function as before (equation 2.2), but the evolution of the economy is now characterized by the following system.

(4.1a) $\dot{k}_t = s_k y_t - (n+g+\delta)k_t$

(4.1b) $\dot{h}_t = s_h y_t - (n+g+\delta)h_t$

(4.1c) $\dot{d}_t = (c+s_k+s_h-1)y_t + (r-n-g)d_t$

(4.1d) $d_t \leq k_t$

where d is the amount of foreign debt borrowed per effective labor unit, and c is the marginal propensity to consume.

The present paper takes the BMS notion of imperfect capital mobility to extend the model of Mankiw, Romer and Weil (1992) to its open economy version. Equation (4.1c) is the point of departure. It specifies the accumulation of debt as a sum of new borrowing in each period and the effective interest accumulation, where c is the consumption rate out of output. The borrowing constraint (4.1d), which has been studied in Chapter 3 as equation (3.1e"), classifies an open economy into two categories: the open economy is credit-constrained if $d_t \leq k_t$ is binding, and credit-unconstrained if $d_t < k_t$ applies[21]. The credit-unconstrained open economy will behave exactly like an open economy under perfect capital mobility. It jumps to the steady state values of k^*, h^* and y^*. In contrast, the credit-constrained economy will adjust very differently toward its steady state. It is precisely on this case that BMS focuses, and derives new results.

In a credit-constrained open economy, since only physical capital serves credibly as collateral, the net return on this capital is still tied to the world interest rate, r^w, at all time

[21] As in the BMS model, the key consideration is whether the initial quantity of assets per effective unit of labor, $k_o + h_o - d_o$, is greater or less than the steady state value of human capital, h^*. If $k_o + h_o - d_o < h^*$, then the constraint is binding, that is, d=k applies.

periods, while output and human capital can only adjust accordingly. This asymmetry between k and h means in equation (4.1a), $\dot{k}$ will fall to a value of zero immediately, which implies

(4.2) $$\frac{k_t}{y_t} = \frac{s_k}{n+g+\delta}$$

Equation (4.2) ensures the ratio of physical capital to output, k_t / y_t, will be constant throughout the transition to steady state.[22] Substituting equation (4.2) into the production function (2.2) gives y as a reduced function of h,

(4.3) $$y_t = Bh_t^{\varepsilon}$$

where $$B \equiv \left(\frac{s_k}{n+g+\delta} \right)^{\frac{\alpha}{1-\alpha}} \quad and \quad \varepsilon = \frac{\beta}{1-\alpha}$$

Given the condition $\alpha + \beta < 1$, it follows that $0 < \varepsilon < \alpha + \beta < 1$. Therefore production function (4.3), like production function (2.2), exhibits positive and diminishing marginal product in human capital h. If we assume that the world interest rate r^w is constant at its steady state, and the home economy is neither more nor less impatient than the world economy, then the steady state is the same as that for the closed economy. So the opportunity to borrow on the world credit market does not influence the steady state (given by 2.4a-2.4c).

4.2 Transitory Dynamics under Imperfect Capital Mobility

The convergence dynamics are also similar to that of the closed economy--both featuring diminishing returns. A similar linearization process as the one derived in Appendix A will produce,

[22] Notably, this result is consistent with one of the Kaldor's (1961) stylized facts about economic development.

(2.7) $$\frac{d\ln y_t}{dt} = \lambda(\ln y^* - \ln y_t)$$

However, it turns out that the speed of convergence is affected by the borrowing opportunity. Specifically, the speed of convergence is now given by

(4.4) $$\lambda = (1-\varepsilon)(n+g+\delta).$$

The above formula corresponds to equation (2.8), which gives the convergence coefficient for the closed economy. The only difference is that in the credit-constrained open economy $\alpha+\beta$ has to be replaced by ε. And since $\varepsilon < \alpha + \beta < 1$, the speed calculated from equation (4.4) will be greater than that calculated from equation (2.8) in the closed economy case. So the partially open economy converges faster than the closed economy. Once again, plugging in $n = 0.01$, $g = 0.02$, $\delta = 0.05$, $\alpha = 0.3$ *and* $\beta = 0.5$, we obtain $\varepsilon = \beta / (1-\alpha) = 0.71$ and $\lambda = 0.0228$ per year, which means the economy will move halfway to its steady state in about 30 years. Recall that the same set of parameters in the closed economy yields an smaller rate of $\lambda = 0.014$, and that the closed economy will move to halfway to its steady state in about 49 years. BMS also experimented with a wide range of reasonable parameter values of $(n, g, \delta, \alpha, \beta)$; each time the predicted convergence coefficient λ fell within the range of empirical estimates, $\lambda \in (0.015,\ 0.035)$ per year.[23]

The time path of income y_t, starting from a initial income level y_0 at t_0, gradually moving toward the steady state level y^*, is once again given by (2.9), reprinted below, except that the rate of convergence is now given by (4.4).[24]

(2.9) $$\ln y_t = (1-e^{-\lambda t})\ln y^* + e^{-\lambda t}\ln y_0$$

[23] BMS (1992), p20.
[24] The derivation of (2.9) is given in a footnote in Chapter 2.

So far, we have encountered three kinds of prototype economies. The closed economy, the open economy with perfect capital mobility, and the open economy with imperfect capital mobility, and have studied their convergence properties in each case. The speed of convergence is the highest for the open economy with perfect capital mobility. Indeed, its speed of convergence is infinity. In contrast, speeds of convergence are finite in both case for the closed and the open economy with imperfect capital mobility, although the credit-constrained open economy converges faster than the closed economy for any given set of parameters. So the credit-constrained open economy behaves much more like the closed economy than the fully open economy: it converges only gradually.

We have thus found at least one way, by introducing the BMS notion of imperfect capital mobility, to overcome the dynamic deficiency of the open economy model with perfect capital mobility. Does this model offer any improvement over previous models when applied to cross-country growth? Three arguments suggest that it does. First of all, the partially open economy is now found to converge only gradually, as dose any real economy. Secondly, the model adds a whole new dimension of open-economy related regularities which were previously treated as omitted variables, and suggests a new test and a revised speed of convergence. Thirdly, one of the key properties of the model, that the capital-output ratio remain constant during the transition toward the steady state, is consistent with one of the stylized facts of economic development articulated by Kaldor (1961).

4.3 Empirical Implications for Respecifing Cross-country Growth

The BMS model reviewed above sheds new light on the empirical convergence literature. At the theoretical level, the model extends the neoclassical growth theory from a closed economy to open economy setting, and in doing so justifies the inclusion of variables such as openness and debt outstanding as explanatory variables in empirical studies. At the empirical level, the model provides a new structural framework with two major extensions to the MRW (1992) model.

The first extension is to revise the modeling of the efficiency parameter, A, to include the country's openness. The role of openness in stimulating labor augmenting technological change is twofold (Knight, Loayza, and Villanueva, 1992). First, the import-export sector serves as a vehicle for technology transfer and provides channels for intersectional external economies. Second, rising exports earnings help to relieve the foreign exchange constraint: that is, they serve to increase the country's ability to service its foreign debt, and ability to import technologically-advanced capital goods.

Recall that in the closed economy model, the change of per capita income from time *0* to *t* is given by (2.10').

(2.10') $$\ln\frac{Y_t}{A_t L_t} - \ln\frac{Y_0}{A_0 L_0} = (1-e^{-\lambda t})\ln y^* - (1-e^{-\lambda t})\ln\frac{Y_0}{A_0 L_0},$$

While in the credit-constrained open economy, (2.10') still apply since the transitory dynamics is essentially the same as in the closed economy model, (except for a different convergence rate λ), we can now respecify that:

(4.5) $$A_t = A_0 e^{gt} T^{\varpi}$$

or

(4.5') $$\ln A_t = \ln A_0 + gt + \varpi \ln T,$$

where g is the exogenous rate of change of labor augmenting technology, and T represents the openness of the economy which facilitates the spread of highest level of existing technology. Substituting (4.5') into (2.10) and simplifying, we get a new specification of income growth as a function of determinants of the steady state and the initial level of income.

$$\ln\frac{Y_t}{L_t}-\ln\frac{Y_0}{L_0}=-(1-e^{-\lambda t})\left(\frac{\alpha+\beta}{1-\alpha-\beta}\right)\ln(n+g+\delta)$$

$$+(1-e^{-\lambda t})\left(\frac{\alpha}{1-\alpha-\beta}\right)\ln s_k+(1-e^{-\lambda t})\left(\frac{\beta}{1-\alpha-\beta}\right)\ln s_h \tag{4.6}$$

$$-(1-e^{-\lambda t})\ln\frac{Y_0}{L_0}+gt+(1-e^{-\lambda t})\ln A_0+\varpi\ \ln T$$

Notice that (4.6) is identical to its closed economy counterpart (2.11), except for the addition of the last term. Since the speed of convergence is greater in this model, $\lambda > 0$ still holds. Therefore, all terms in the specification still have the same expected signs as in the closed economy model. Particularly, the "conditional convergence" captured by the fourth term is still valid in this partially closed economy: for countries have the same saving rates, population growth and same degree of openness, poor countries grow faster per capita, since their initial income levels are further below their steady state position.

The second extension from the MRW model is concerned with the foreign debt variable. Its inclusion is more complex and not as straightforward as the inclusion of the trade variable. As shown above, explanatory variables in the income growth equation (4.6) include the determinants of the steady state and initial income, as in the closed economy case, since the two economies share the same steady state. Debt does not appear directly as an extra explanatory variable in the growth equation. However, debt does affect growth indirectly in two ways in the case of credit-constrained open economy. First, it suggests to us to expect a different set of coefficients from (4.6) by altering the rate of convergence, λ. Second, the introduction of the debt variable questions the exogeneity of the savings rate (as a proxy of investment), s_k.

Until now, we have ignored the potential endogeneity of the saving ratio. Although exogeneity has been a reasonable approximation in a closed economy, arguments can be made that such is not the case in an open economy with any degree of physical capital mobility. Specifically, unlike other determining factors of national saving rate such as life time income, time preference, population growth and so on, the role of taxes changes dramatically from closed to open economy settings (Feldstein and Horioka, 1980). This result is especially relevant for the taxing effect of the excessive foreign debt, as forcefully captured by the concept of "Debt Laffer Curve" (Krugman, 1988) and the empirical evidence supporting the existence of such curves for various countries (Claessens, 1990, Dean and Xu, 1991, 1993).

Consider the problem of determining an optimal savings policy in the presence of taxes. In a closed economy, the national return on additional saving is the domestic marginal product of capital, regardless of the tax rates. Suppose a proportional tax at rate τ on firm's output is introduced so that the representative firm chooses to maximize its after-tax cash flow. Consequently, the net yield that individual investors receive is lowered by taxes on capital income. However, the nation as a whole receives both the after-tax yields and the tax revenue; it is the pretax marginal product of capital that should influence national saving policy in a closed economy.

In contrast, if capital is mobile between countries, and if debt service payments to foreign creditors constitute a tax on domestic savings, the yield to the home country on the additional saving is only the after-tax return received by the investors and not the pretax marginal product of capital. So tax rate becomes a critical consideration in determining the saving rate, and a higher tax rate will induce a lower saving rate.

Here, tax rate τ should be interpreted broadly to include various elements that affect the incentives to accumulate physical capital.[25] It is particularly relevant in the credit-constrained economy case that τ should include the disincentives to invest associated with an excessive foreign debt burden if Ricardian individuals rationally anticipate the implied future liabilities.

The 1980s have witnessed a spectacular decrease of investment in the severely indebted developing countries. Direct evidence on Latin American countries in particular seems to suggest that the attempt to service the debt created tremendous domestic pressure that eventually brought investment down. In the LDC debt literature, this negative correlation between debt and

[25] Some examples are given by BMS in their paper, such as the risk of expropriation by the government, strong labor unions and foreign invaders.

investment has been known as a "debt overhang problem" (Sachs, 1989). Debt acts as a tax on the domestic economy, and too much of it may create a "debt Laffer curve" problem (Krugman, 1988).

All these suggest that for the growth equation to be estimated consistently, it should be estimated from a simultaneous equation system that contains, in addition to the growth equation, an equation for investment that accounts for, among other things, debt and trade variables.

To sum up, at the empirical level, the BMS model provides a new structural framework with the following implications:

(1) It suggests a new definition of conditional convergence: the conventional definition of convergence in growth rate after controlling for initial income level, human capital, population growth, plus a new factor, the country's external borrowing and current account conditions. The rate of this convergence should be expected to differ from what was previously inferred from the closed economy model.

(2) Under the assumptions of open economy and imperfect capital mobility, the model identifies additional determinants of saving and investment. In particular, the model provides a way in which one can incorporate the theoretical result of "debt Laffer curve" from the LDC debt literature into cross country growth literature. Given that some economies are credit-constrained, if one is concerned with conditional convergence in real per capita growth rate, as we will be in Chapter 6 and 7, one would expect to find a direct effect of indebtedness on growth, saving and investment, and also during the transitional process, an indirect effect on growth rate via investment.[26]

Two caveats of this model deserve attention. One is associated with the BMS specific notion of capital mobility. By assuming that physical capital can be collateralised fully in the international loan markets, it is in effect assuming physical capital is perfectly mobile, an

[26] If instead, one is concerned with convergence in levels of per capita income as in sections I and II of Mankiw, Romer and Weil (1992), one should certainly expect an effect of saving, since saving is a level effect that enters the determination of all level variables directly.

assumption that is hard to justify given that international loan markets are imperfect. It requires perfect information (about amount of physical capital to set up the upper limit of lending to a particular country), and full enforceability (on attaching the physical capital of a potentially defaulting debtor). Both are absent from international loan markets.

Another caveat obviously is that it permits no room for modeling structural change in the growth and borrowing process, when in fact we know the borrowing and debt servicing process is characterized by regime switching that took place from 1970s to 1980s (Cohen, 1993). One component of this regime switching was an aggregate shock in the form of sharp rises in world interest rates, and consequently much higher borrowing costs to all debtors alike. Another component of it was country-specific in nature. This second component was the one referred to in the debt-overhang literature: how much debt did a country has to service? Is the country moving from being credit-unconstrained to credit-constrained? What are the effects of this switching on the country's investment and therefore growth? And finally, what are their implications for cross country growth? To study these issues we need a model in which optimal saving and income are simultaneously determined while taking into account the imperfect operation of international loan markets. It is to such an alternative model we now turn.

Chapter 5 An Optimal Growth Model with a Foreign Borrowing Constraint

5.1 The Model

In this chapter, an optimal growth model will be constructed for a small borrowing economy which faces a foreign borrowing constraint (FBC), drawing upon previous models by Blanchard and Fischer (1989, Ch. 2.4) and Isgut (1993).[27] All assumptions made in Chapters 2 and 3 regarding the utility function and the production are maintained. All variables and parameters are as defined earlier in Chapters 3 and 4 unless specified otherwise. For the sake of tractibility, we again abstract from modeling human capital which would not affect any key results of the model since the FBC depends on the country's ability to finance physical capital. Also, to simplify the exposition, time subscripts will be omitted when doing so creates no confusion. It should be understood that all variables in this dynamic system are functions of time, t. With all this in mind, the small open economy's maximization problem will be given by the following:

$$\underset{\langle i,c \rangle}{Max} \quad U_0 = \int_0^{\infty} u(c)\, e^{-(\theta - n)t}\, dt \qquad \text{[in per capita terms]}$$

subject to

$$\dot{k} = i - (n+\delta)k$$

$$\dot{b} = (\theta - n)b + m \qquad \text{[m = net imports = trade deficit]}$$

$$c = f(k) + m - i - \frac{a}{2}i^2$$

$$b \leq B \quad \text{for all } t \in [0, \infty) \qquad \text{[foreign borrowing constraint]}$$

and k_0, b_0 *given*

where $\dot{b} \equiv \dfrac{db}{dt}$ *and* $\dot{k} \equiv \dfrac{dk}{dt}$

$$c, k \geq 0 \quad \forall t,$$

[27] Yet, the present model is not exactly identical to either of these two models. As we pointed out earlier, the Balnchard and Fischer model will serve as a benchmark model of open economy growth with perfect capital mobility, which will be reduced to one of the special cases in the present model. The Isgut model, while is more closely related to the present model, tends to handle some issues that can usually only be raised in two-sector models in a essentially one-sector model. As a result, the model's numerical solutions need to be doubled-checked.

That is, the agent maximizes the present discounted value of its utility from consumption, subject to a *dynamic budget constraint, the transversality condition,* and *the foreign borrowing constraint.* Notice this formulation is identical to the benchmark model set up in Chapter 3 except for three modifications. First, the No-Ponzi-Game condition (1e) is replaced by the foreign borrowing constraint (1e'), which changes the model from a Group A model to a Group B model. Secondly, to add more realistic flavor we incorporate a non-zero adjustment cost term for investment, the term $(a/2)i^2$, where a is a positive fraction. This is a system with two state variables: k and b, and two control variables i and c (or alternatively i and m), as in the benchmark model.[28] And finally, we have set the growth rate of labor-augmenting technology g to zero, as has been done in Isgut (1993), so that our results will be comparable with his study. Extending the basic results to a scenario with positive technological growth will be straightforward.

Technically, this model involves a state-space inequality constraint, i.e.,

$$b \le B,$$

and consequently the standard maximum principle can not be applied directly. We modify the solution procedure by the *indirect adjoining approach* as follows.[29] First of all, rewrite the state-space inequality constraint in a form that can be incorporated into maximum principle. The idea is simple: since debt b_t is not allowed to exceed B, then whenever $b_t = B$ (the constraint becomes binding) we must forbid debt to increase. This can be accomplished simply by rewriting the FBC as

$$\frac{db}{dt} \le 0 \qquad [\text{whenever } b_t = B]$$

or

$$\dot{b} = (\theta - n)b + m \le 0 \qquad [\text{whenever } b_t = B]$$

[28] Consumption and net imports are linked through the intertemporal budget constraint and therefore are not independent of each other as control variables.

[29] For more details on this procedure, see Chiang (1992, Ch. 10.3-4) and Long and Vousden (1977).

The second step is to form the standard current-value Hamiltonian *without the foreign borrowing constraint:*[30]

$$H_c = U(c) + \lambda[i - (n+\delta)k] + \mu[(\theta - n)b + m],$$

where λ and μ are the two costate variables for k and b, respectively. They can be interpreted as the shadow prices of capital and foreign debt.

In step three, the current-value Hamiltonian is augmented by the rewritten version of the foreign borrowing constraint to form the current-value Lagrangian $L_c = H_c - \eta \dot{b}$, where η is a Lagrangian multiplier. That, after substituting for the expression of c, is

$$L_c = U\left[f(k) + m - i - \frac{a}{2}i^2\right] + \lambda[i - (n+\delta)k] + \mu[(\theta - n)b + m] - \eta[(\theta - n)b + m].$$

Finally, applying the maximum principle to the Lagrangian and supplementing with appropriate additional conditions, yields the following set of first order necessary conditions.

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[30] When the constrained problem involves a discount factor, it is desirable to use the current-value Hamiltonian H_c, instead of the present value Hamiltonian H, since the former allows the use of phase-diagram by surpressing the explicit time variable.

Revised Maximum Principle:

(5.1) $\frac{\partial L_c}{\partial i} = -U'(c)(1+ai) + \lambda = 0$ [L_C maximized w.r.t. i]

(5.2) $\frac{\partial L_c}{\partial m} = U'(c) + (\mu - \eta) = 0$ [L_C maximized w.r.t. m]

(5.3) $\dot{k} = i - (n+\delta)k \quad [\frac{\partial Lc}{\partial \lambda}]$ [equation of motion for k]

(5.4) $\dot{b} = (\theta - n)b + m \quad [\frac{\partial Lc}{\partial \mu}]$ [equation of motion for b]

(5.5) $\dot{\lambda} = -\frac{\partial L_c}{\partial k} + (\theta - n)\lambda$ [equation of motion for λ]

(5.6) $\dot{\mu} = -\frac{\partial L_c}{\partial b} + (\theta - n)\mu$ [equation of motion for μ]

(5.7) $\lim_{t\to\infty} \lambda\, e^{-(\theta-n)t} = 0$ [(5.7) and (5.8) are transversality

(5.8) $\lim_{t\to\infty} -\mu\, e^{-(\theta-n)t}[b - B] = 0$ conditions for this special case.]

(5.9) $k_0,\ \ b_0\ \ given$ [initial conditions]

(5.10) $b \le B \qquad \eta(B-b) = 0$ [complementary-slackness]

(5.11) $\frac{\partial L_c}{\partial \eta} = -\dot{b} = -(\theta - n)b - m \ge 0 \qquad \eta \ge 0 \qquad \eta\dot{b} = 0$

(5.12) $\frac{d\eta}{dt} \le 0$ [=0 when b≤B]

Equations (5.1)-(5.9) are the modified maximum-principle conditions which hold whether or not the constraint b=B is binding. These include maximizing conditions with respect to each control variables (5.1)-(5.2), equations of motions for each state and costate variables (5.3)-(5.6), transversality conditions (5.7)-(5.8), and initial condition (5.9). Equation (5.10) is a complementary-slackness condition which helps to switch the system between the unconstrained and constrained regimes. For example, b<B (constraint not binding) would mean η=0, which would cause the last term in L_C to drop out, and thereby nullify the conditions regarding $\frac{\partial L_c}{\partial \eta}$ and $\frac{d\eta}{dt}$, i.e. equations (5.11) and (5.12). In this case the conditions reduced to equations (5.1)-(5.9)

with η set to zero in (5.2), exactly identical to our benchmark model of open economy with perfect capital mobility outlined in Section 2.

Conversely, when b=B (constraint binding), we intend the complementary-slackness condition to imply $\eta>0$.[31] Thus equations (5.11)-(5.12) will only be active when *the foreign borrowing constraint is binding* after equation (5.10) is switched on. Finally, under this approach, the behavior of η and its effects on the system are more explicitly depicted by equation (5.12). For example, if the country is hit by its credit ceiling, η will jump from zero to a positive level, the system will adjust to a positive η in equation (5.2) so that the current account is restricted from running a deficit.

Under this framework, a small borrowing economy can be classified into one of the three cases: never-constrained, ever-constrained, and optimal regime switching, depending on the relationship among initial debt level b_0, steady-state debt level b^*, and credit ceiling B. Assuming debt increases monotonically from b_0 towards its steady-state level b^*, a country is *never-constrained* if $b_0<b^*<B$: i.e., its foreign debt under optimal growth never reaches its credit ceiling B. In this case the country behaves as if it is facing a perfect capital mobility. A country is *ever-constrained* if $b_0 \geq B$: i.e., its initial debt level b_0 has already reached B and therefore no borrowing can occur during the planning horizon. In this case, the optimization is in effect carried out in financial autarky. A country will pursue *optimal regime switching* if $b_0<B<b^*$: i.e., the country can borrow more debt than its initial level but will eventually be hit by FBC at B before reaching unconstrained steady-state level b^*. In this event, it is optimal for the country to borrow up to its credit ceiling, B, then service the debt thereafter. It is easy to see that the first two theoretical limiting cases are identical to the standard neoclassical growth models of an open and closed economy. We now characterize the solutions under these three possible cases.

[31] This is a stronger form of of complementary-slackness, since in the normal interpretation, b=B is consistent with $\eta=0$ as well as $\eta>0$.

5.2 A Never-Constrained Economy

As is made clear earlier, a country is *never-constrained* if $b_0<b^*<B$, where b_0 is the initial level of debt, b^* the unconstrained steady-state level, and B the credit ceiling. This is a case when the FBC is not binding throughout the planning horizon, a case in which a country never has to worry about its foreign borrowing constraint. It can simply borrow as much as it desires at the going interest rate θ. The model is then reduced to a special case which is identical to our benchmark model--the open economy model with perfect capital mobility--outlined in Chapter 3. The solution in this case is characterized by the standard maximum principle. In terms of our revised maximum principle, this case amounts to when $\dot{b} \le 0$ is never binding, therefore $\eta=0$ from (5.10), and (5.11) and (5.12) disappear from the condition set.

Assuming an interior solution, the revised maximum-principle conditions are reduced to the following set:

(5.1)	$\frac{\partial L_c}{\partial i} = -U'(c)(1+ai)+\lambda = 0$	[L_c be maximized w.r.t. i]
(5.2)	$\frac{\partial L_c}{\partial m} = U'(c)+\mu = 0$	[L_c be maximized w.r.t. m]
(5.3)	$\dot{k} = i-(n+\delta)k \quad [\frac{\partial Lc}{\partial \lambda}]$	[equation of motion for k]
(5.4)	$\dot{b} = (\theta-n)b+m \quad [\frac{\partial Lc}{\partial \mu}]$	[equation of motion for b]
(5.5)	$\dot{\lambda} = -\frac{\partial L_c}{\partial k}+(\theta-n)\lambda$	[equation of motion for λ]
(5.6)	$\dot{\mu} = -\frac{\partial L_c}{\partial b}+(\theta-n)\mu$	[equation of motion for μ]
(5.7)	$\lim_{t\to\infty} \lambda\, e^{-(\theta-n)t} = 0$	[(5.7) and (5.8) are transversality
(5.8)	$\lim_{t\to\infty} -\mu\, e^{-(\theta-n)t}[b-B] = 0$	conditions for this special case.]
(5.9)	$k_0,\ b_0$ *given*	[initial conditions]

First, we derive the path of consumption. Consumption is constant over time, sufficient amount of credits helps to make a complete consumption-smoothing. Expanding equation (5.6), we get

$$\dot{\mu} = -\frac{\partial L_c}{\partial b} + (\theta - n)\mu = -(\theta - n)\mu + (\theta - n)\mu = 0.$$

This implies a constant saddle price of debt over the course of transition, i.e.

$$\mu = const.$$

The last equation, together with equation (5.2), yields

$$U'(c) = \mu = const.$$

In other words, the marginal utility during the course of transition stays constant. This corresponds to a unique level of consumption given the assumptions made earlier on the shape of the consumption function so that,

$$c = const = \bar{c} \qquad \text{for all } t \in [0, \infty).$$

This constant level of consumption can easily be derived by employing equations (5.4) and flow budget constraint (5.13), both are given below.

(5.4) $$\dot{b} = (\theta - n)b - m$$

(5.13) $$\bar{c} = f(k) + m - i - \frac{a}{2}i^2$$

Substitute m from (5.13) into (5.4), we get

(5.14) $$\dot{b} = (\theta - n)b + \left[\bar{c} - \left(f(k) - i - \frac{a}{2}i^2\right)\right].$$

Equation (5.14) is a first order differential equation of b with variable coefficients. Solve it by integration, the solution give the time path of debt at each point in time. The derivation of $b(t)$ is done in Appendix B.

$$b = \frac{\bar{c}e^{(\theta - n)t}}{\theta - n} - e^{(\theta - n)t}\left[\int_0^\infty [f(k) - i - \frac{a}{2}i]e^{-(\theta - n)t}dt\right]$$

Substitute the initial condition into this time path of debt, $b(0) = b_0$ at $t = 0$, thus

$$b_0 = \frac{\bar{c}}{(\theta - n)} - \int_0^\infty\left[f(k) - i - \frac{a}{2}i^2\right]e^{-(\theta - n)t}dt.$$

Therefore, the constant level of consumption is determined by

$$\text{(5.15)} \qquad \bar{c} = (\theta - n)\left[b_0 + \int_0^\infty e^{-(\theta - n)t}[f(k) - i - \frac{a}{2}i^2]dt\right].$$

Equation (5.15) asserts that consumption is solely determined by the present discounted value of net output, adjusted for the initial debt level. For a given present discounted value of output the timing of consumption is completely separated from that of production.

We now move to solve for the time paths of other variables in the system, paths of debt, capital, and investment. Conceptually this is possible since we can solve for four variables (b(t), m(t), k(t), and i(t)) from four equations of motion (5.3)-(5.6). However with consumption staying constant, we can simplify the matter by first solving a 2×2 system of k(t) and i(t) which is independent of paths of b(t) and m(t), and then solving for the paths of other variables by substitution. We can derive this subsystem of investment and capital by manipulating (5.1) and (5.5).

(5.1) $$\frac{\partial L_c}{\partial i} = -U'(c)(1+ai) + \lambda = 0$$

(5.5) $$\dot{\lambda} = -\frac{\partial L_c}{\partial k} + (\theta - n)\lambda = -U'(c)f'(k) + (n+\delta)\lambda + (\theta - n)\lambda$$

or

$$\dot{\lambda} = -U'(c)f'(k) + (\delta + \theta)\lambda$$

Rewrite (5.1), we get

(5.1)' $$\lambda = (1+ai)U'(c).$$

Differentiate (5.1)' with respect to t, yields the following relation

(5.16) $$\dot{\lambda} = U''(c)\dot{c}(1+ai) + U'(c)(a\dot{i}).$$

The growth path of λ can be obtained by dividing (5.12) by (5.1)'.

(5.17) $$\frac{\dot{\lambda}}{\lambda} = \frac{U''(c)\dot{c}(1+ai) + U'(c)(a\dot{i})}{(1+ai)U'(c)} = \frac{U''(c)}{U'(c)}\dot{c} + \frac{a}{1+ai}\dot{i}$$

(5.17) is one way to express $\dot{\lambda}/\lambda$.

Alternatively, we can get this ratio by using (5.5) and (5.1)'. By first getting U'(c) from (5.1)', and then substituting it into (5.5), we have

(5.18) $$\dot{\lambda} = \frac{\lambda}{1+ai} f'(k) + (\delta + \theta)\lambda \ .$$

By dividing λ throughout we get *another way to express* $\dot{\lambda}/\lambda$.

Next, equating two expressions of $\dot{\lambda}/\lambda$ from equation (5.17) and (5.18), we have

(5.19) $$\frac{U''(c)}{U'(c)}\dot{c} + \frac{a}{1+ai}\dot{i} = -\frac{f'(k)}{1+ai} + (\delta + \theta).$$

This last equation can be simplified to

(5.20) $$\dot{i} = -\frac{1+ai}{a}\left[\frac{f'(k)}{1+ai} - \delta - \theta\right],$$

if and only if $\frac{U''(c)}{U'(c)}\dot{c}=0$, which is true in the present case of constant consumption confirmed earlier. This equation (5.20), together with equation (5.3), jointly determine the paths of k(t) and i(t) independent of paths b(t) and m(t).

Now suppose that the neoclassical production function is given by a Cobb-Douglas form, $f(k) = k^{\beta}$ $(0 < \beta < 1)$, then the system of (non-linear) first order differential equations becomes,

(5.3)' $$\dot{k} = -(n+\delta)k + i$$

(5.20)' $$\dot{i} = -\frac{\beta}{a}k^{\beta-1} + (\delta+\theta)i + \frac{(\delta+\theta)}{a},$$

which is completely independent of other variables.

A **steady state** exists and is defined as (k^*, i^*) which satisfies $\dot{k} = \dot{i} = 0$, or

(5.21a) $$-(n+\delta)k^* + i^* = 0$$

(5.21b) $$-\frac{\beta}{a}(k^*)^{\beta-1} + (\delta+\theta)i^* = \frac{(\delta+\theta)}{a}$$

This leaves two equations (alas non-linear) with two unknowns. In principle, the steady state level of capital and investment can be obtained by solving (5.21a) and (5.21b).

It can be shown that the linearized system (k, i) is dynamically stable. To check the stability of the system, all that is required is to find its characteristic roots. This is carried out in Appendix C. The system has two real, yet distinct characteristic roots, one is positive and the other negative. Therefore we conclude that there exists a saddle point steady-state equilibrium which is dynamically stable along the saddle path.

Finally, (5.21a) and (5.21b) define steady state equilibrium pair (k^*, i^*) as functions of the parameters, n, δ, θ, β and a, that is

(5.22a) $k^* = f(n, \delta, \theta, \beta, a)$

(5.22b) $i^* = g(n, \delta, \theta, \beta, a)$.

Results of comparative static analysis around the steady state equilibrium are summarized in Table 2. Readers interested in the derivation of these results are referred to Appendix D.

sign of the change	population dn.	depreciation $d\delta$	interest rate $d\theta$	capital share $d\beta$	adjustment cost da
capital, dc^*	-	-	-	+	?
investment, di^*	+	?	-	+	?

Table 2: Results of Comparative Static Analysis

In steady state with a higher rate of population growth, the per capita capital stock is lower and the rate of investment is higher, simply because output is shared by more population. With a higher depreciation rate, the economy converges to a steady state with a lower level of capital stock because of faster wear and tear. But the effect on steady-state investment is ambiguous since on the one hand, faster wear and tear requires higher investment to replace the depreciated capital, on the other hand high depreciation means the effective rate of return is lower and thus discourages investment.

It is hardly surprising that the steady-state capital stock and investment rate both go down as the interest rate increases. This is particularly relevant to the events of late 1970's. An aggregate shock in the form of a higher interest rate might have caused borrowing economies to shift to a new steady state with a lower investment and capital stock even in the long run. Conversely, the steady-state capital stock and investment rate both go up as capital share increases in the production function. Finally, the effects of a higher adjustment cost are ambiguous for both capital stock and investment variables. But for reasonable parameter values, both will be adversely affected, as confirmed by intuition.

5.3 An Ever-Constrained Economy

A small borrowing economy is ever-constrained if $b_0 \geq B$. Since no borrowing occurs during the entire planning horizon, the level of debt throughout remains at the initial level. This is another special case of our general maximization problem: the ever-constrained case is analytically equivalent to the closed economy case. With $b_0 = b_t = B$ for each period, the balance of payments is at equilibrium in each period. Net imports also become constant, i.e. $\overline{m} = -(\theta - n)b_0$. There is only one state variable left in the system, capital k. Either consumption or investment can serve as a control variable, but not both. The maximization problem is reduced to a simpler form that is akin to the planner's problem in a closed economy.

$$\underset{\langle i \rangle}{Max} \quad U_0 = \int_0^\infty u(c)\, e^{-(\theta - n)t}\, dt \qquad \text{[in per capita terms]}$$

$$\begin{aligned}
&\textit{subject to} \quad && \dot{k} = i - (n + \delta)k \\
& && c = [f(k) - (\theta - n)b_0] - i - \frac{a}{2}i^2 \\
& && b_0 = b_t = B \quad \text{for all } t \in [0, \infty) \quad \text{[foreign borrowing constraint]} \\
&\textit{and} && k_0, b_0 \;\; \textit{given}
\end{aligned}$$

Instead of solving for analytical solutions as we did for the never-constrained case, we use an alternative approach, phase diagrams. This approach has the advantage that it clarifies the qualitative nature of the solution and allows us to compare this ever-constrained case with the never-constrained case studied earlier. Most phase diagrams in the closed economy growth literature are graphed in the (k,c) space and are familiar to economists. But with the presence of adjustment costs, it is more convenient to study the system in (k,i) space. From (5.3) and (5.19), we can form the following dynamic (k,i) system:

(5.3) $$\dot{k} = -(n+\delta)k + i$$

(5.19) $$\dot{i} = -\frac{1+ai}{a}\left[\frac{f'(k)}{1+ai} - \delta - \theta + \frac{U''(c)}{U'(c)}\dot{c}\right]$$

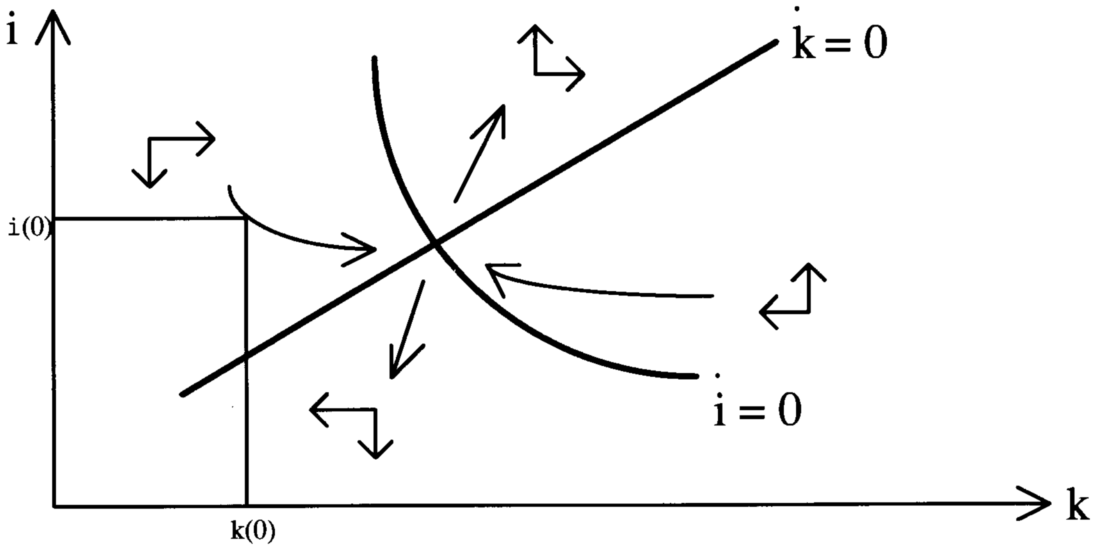
Recall in the never-constrained case that $\frac{U''(c)}{U'(c)}\dot{c}=0$, since consumption is completely smoothed out thanks to the unconstrained borrowing opportunity. By contrast, in the present ever-constrained economy, consumption is no longer constant; therefore $\frac{U''(c)}{U'(c)}\dot{c}\neq 0$. This term captures the difference between the two cases. Furthermore, as can be shown from (5.2), (5.6) and (5.11), consumption increases monotonically, but at a decreasing rate, until a steady state is reached where $\dot{c}=0$:

(5.23) $$\dot{c} = \frac{-\theta\eta + \dot{\eta}}{U''(c)} > 0$$

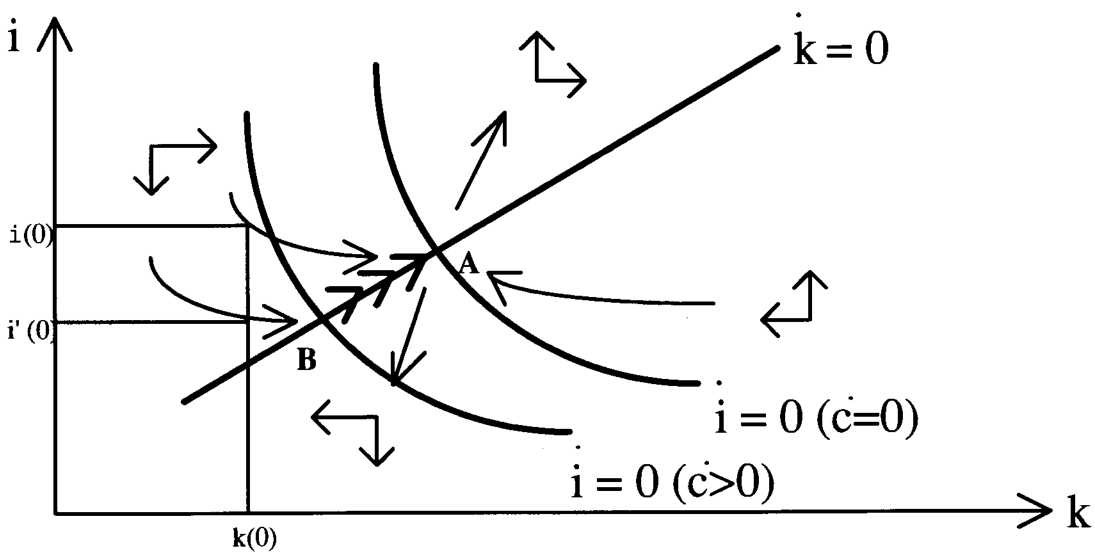
The absolute value of $\frac{U''(c)}{U'(c)}\dot{c}$ represents the scarcity value of foreign debt when the country is credit constrained.[32] It can be interpreted as the interest differential between the domestic and international interest rates.

In both cases, the evolution of the system toward the steady state can be analyzed by the phase diagram in Figure 2. Panel (a) depicts the adjustment process for the never-constrained case. The $\dot{k}=0$ locus is given by $i=\delta k$ and the $\dot{i}=0$ locus is given by $f'(k)=(\delta+\theta)(1+ai)$. The equilibrium trajectory in this case is given by the saddle path. Any pair of initial conditions (k_0, i_0) starting from the stable trajectory will converge to a steady state, the intersection of the $\dot{i}=0$ and $\dot{k}=0$. Starting from a lower level, capital increases monotonically during the transitory process, while investment decreases monotonically as diminishing returns set in eventually.

[32] This term is negative, given the positive and diminising marginal utility function.



(a) A never-constrained economy



(b) An ever-constrained economy

Figure 2: Phase Diagram of Capital and Investment

Panel (b) depicts the adjustment process for the ever-constrained case. The $\dot{k}=0$ locus will not be affected, but the $\dot{i}=0$ locus will. Instead of being given by $f'(k)=(\delta+\theta)(1+ai)$, the $\dot{i}=0$ locus is now determined by $f'(k)=(\delta+\theta-\frac{U''}{U'}\dot{c})(1+ai)$, which shifts the original $\dot{i}=0|_{\dot{c}=0}$ curve to the left given the assumption of diminishing marginal utility. This additional term $\frac{U''(c)}{U'(c)}\dot{c}$ will shrink in absolute value as time passes by, thus moving $\dot{i}=0|_{\dot{c}>0}$ back toward $\dot{i}=0|_{\dot{c}=0}$. And ultimately, the steady state, point A, is decided once again by the two curves $\dot{k}=0$ and $\dot{i}=0|_{\dot{c}=0}$.

Although the ever-constrained and never-constrained economy will reach the same steady state ultimately, the adjustment process takes much longer in the ever-constrained case. To start with, for a given initial capital stock k_0, initial investment in the ever-constrained case is much lower, i.e. $i'_0 < i_0$. Capital accumulation has to proceed at a slower pace because any investment can only be achieved at the expense of consumption, now that the country is deprived of the privilege of external financing. In addition, the investment path does not have to be monotonic as the $\dot{i}=0|_{\dot{c}=0}$ locus keeps shifting toward $\dot{i}=0|_{\dot{c}=0}$ (indicated by arrows in panel (b)), and the economy will ultimately end up at point A rather than point B. Convergence in this case will take much longer.

This analysis sheds some light on the experience of the poorest African countries. Unable to borrow in international loan markets at the going interest rate, they have had long a struggle with insufficient investment and prolonged poverty. For these countries to receive an initial push onto a sustained growth path, aid from multinational organizations is critical.

5.3 An Economy of Optimal Regime Switching

Assuming a country's debt level increases monotonically from initial level b_0 to unconstrained steady-state level b^*, the country will pursue *optimal regime switching* if its credit ceiling B is such that $b_0<B<b^*$; i.e., the country can borrow more debt than its initial level but will eventually be hit by FBC at B before reaching unconstrained steady-state level b^*.[33] At that point, the country will optimally switch from credit unconstrained to constrained regimes in the sense that such a path of consumption maximize the present discounted value of total utility.

Assume the country switches regime at time τ, then the dynamic paths of consumption and investment can be described completely by (5.15) and (5.20) before τ, and by (5.23) and (5.19) after τ.

i. e.,

For all $t \in [0, \tau-]$

$$\bar{c} = (\theta - n)\left[b_0 + \int_0^\infty e^{-(\theta-n)t}[f(k) - i - \frac{a}{2}i^2]dt\right]$$

$$\dot{i} = -\frac{1+ai}{a}\left[\frac{f'(k)}{1+ai} - \delta - \theta\right]$$

For all $t \in [\tau+, \infty)$

$$\dot{c} = \frac{-\theta\eta + \dot{\eta}}{U''(c)} > 0$$

$$\dot{i} = -\frac{1+ai}{a}\left[\frac{f'(k)}{1+ai} - \delta - \theta + \frac{U''(c)}{U'(c)}\dot{c}\right]$$

We can speculate on the shape of consumption path. It would be constant from time t=0 to τ and after that increasing at a decreasing rate. The fact that consumption is increasing in the constrained phase seems to be counterintuitive. One reason is that consumption can not be constant in the constrained phase precisely because the lost of borrowing opportunity makes it impossible to achieve consumption smoothing. Consumption increases simply because output rises in time. The paths of other variables are difficult to solve analytically in this regime-switching case. To gain more insights we provide, as an alternative, numerical solutions.

The choice of parameters is reported in Table 3. The capital share is representative of developing countires' experience. The interest rate and adjustment cost parameters are those most commonly employed in the literature. The credit ceiling for the optimal regime switching case is chosen to represent about seventy percent of GDP of the switching period. It is

[33] It can be shown that this is a sufficient condition for optimal regime switching.

reasonable to believe that at such a level of debt outstanding creditors will be reluctant to lend more.

Capital share	$\beta = 0.5$
Adjustment cost parameter	$a = 0.025$
Depreciation rate	$\delta = 0.10$
Interest rate	$\theta = 0.05$
Initial capital	$k_0 = 100$
Initial debt	$b_0 = 5$
Credit ceiling	$B = 40$

Table 3. Choice of Parameters

We present the simulation results in Figure 3, which compares the time paths of debt, consumption and investment in the never-constrained case with those of optimal regime switching.[34] We now summarize the main results.

(1) Given the choice of parameters, regime switching occurs at around the seventh year.

(2) Clearly, the switching time is endogenous. It depends on the initial levels of investment and consumption. Higher initial values will cause the constraint to bind earlier.

(3) The initial levels of consumption and investment have to be lower than they are under the never-constrained case; otherwise debt would have to reach a level that is higher than B at the switching time, thus violating the FBC constraint.

(4) In the regime-switching case, consumption is lower but constant during the unconstrained phase, and rises monotonically, converging slowly to a new steady state.

(5) Starting from the same initial level, foreign debt rises during the unconstrained phase at a lower rate relative to the never-constrained case, in anticipation of the upcoming credit constraint. Optimality guarantees that the debt path is tangent to the constraint B at exactly the switching time.

[34] Additional paths of capital stock, output and growth rate are also generated, and are available upon request. These additional results are important for testing the model empirically.

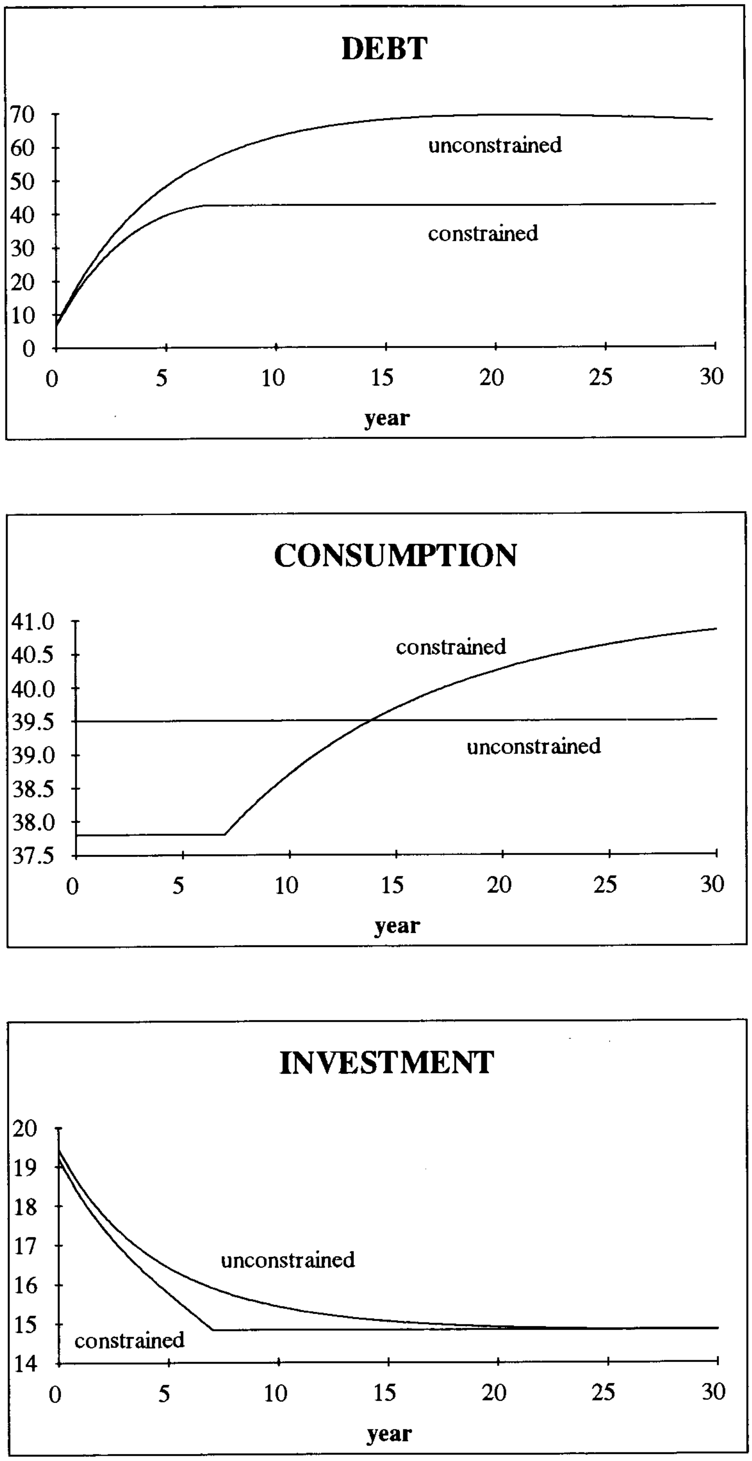


Figure 3. Simulation Results: Time Paths of Debt, Consumption and Investment

(6) In the regime-switching case, the investment path has a peculiar shape. It starts from a lower initial condition, declines at a steeper rate until it reaches the switching time where it stays constant after that. In the medium run, especially from year five to twelve, investment is in general lower than the never-constrained case.

(7) Although the paths of consumption and investment are kinked, they are nonetheless continuous. This property can be proven by the no intertemporal arbitrage condition or by Ramsey's principle.[35]

5.5 Empirical Implications

In this chapter, we studied three possible adjustment processes of a small open economy under a more realistic assumption of imperfect capital mobility. The case of optimal regime switching is particularly relevant to the cross-country growth literature. It offers a plausible explanation for the empirical puzzle that in the past two decades, African and Latin American countries have grown systematically slower than the sample mean, as captured by the significantly negative regional dummies.

Until now, the external adjustment process and its effects on growth have largely been overlooked in the empirical growth literature. The literature has focused on testing the conditional convergence hypothesis derived from closed economy optimal growth model: that is, controlling for population growth, accumulations of human and physical capital, countries should converge in their per capita income, and with lower initial incomes poor countries tend to grow faster then the rich countries. The present model sheds some new light on the empirical convergence literature. Like the BMS model presented in the previous chapter, this model extends the neoclassical growth theory from a closed economy to open economy setting under the assumption of imperfect capital mobility, and in doing so justifies the inclusion of variables such as debt outstanding and openness as explanatory variables in empirical studies.

[35]As investment and consumption are control variables, they can jump in theory. Therefore, they are not necessarily continuous.

Moreover, the present model offers a much richer structure than the previous BMS model. In this model, not only can external variables such as debt act as instruments of investment financing, structural adjustment and stabilization, they can also have long run growth effects. For example, a regime-switching economy converges to a different steady state from the other two cases. Furthermore, although the never-constrained and ever-constrained economies ultimately converge to the same state, in the latter case initial level of investment is very low and insufficient, and convergence takes painfully long. Convergence should occurs within "clubs", rather than between them (Baumol, 1986).

Baumol hypothesizes that there were three "growth clubs" at different stages of development, and observes that income levels converge within the richest "club" and that the poorest "club" falls behind the rest substantially. Dowrich and Gemmell (1991) identifies these three "clubs" empirically as divided by two jointly significant structural breaks by levels of labor productivity, at 41% and 13% of US levels. The upper break point separates the "rich" from "middle income" countries as straddled by Greece, Uruguay, and Argentina. The lower break point groups the poorest 29 countries, which are almost all African. Not unexpectedly, the marginal product of capital in these poor countries is considerably lower than in the richer countries, suggesting that capital is not highly mobile between these groups. They interpret this as evidence supporting the hypothesis that technological spillover assists productivity growth in countries at a medium level of development but is unavailable to the least developed countries, since the levels of infrastructural development in these poorest countries are below the threshold level which is required for assimilation of technological diffusion.

If we assume that a country's income level is positively correlated with its ability to borrow internationally, and thus being "rich", "middle income" and "poor" correspond to having "high", "moderate" and "low or zero" credit ceilings, then their empirical fundings of "rich", "middle income" and "poor" clubs coincide nicely with our classification of "never-constrained", "optimal regime-switching" and "ever-constrained" groups. Therefore our model offers an alternative and complementary explanation for the existence of the three "clubs"; access to international credit markets is as important as the threshold level of infrastructure. Both models confirm that empirically, it is not appropriate to group all countries together, credit-constrained and credit-unconstrained, to perform cross-country regressions. If one does so, these structure differences will inevitably show up. Given the fact that the "ever-constrained" club consists of mostly African countries, and the "optimal regime-switching" club is dominated by Latin American debtors, it is no surprise that they show up as African and Latin American dummies in cross-country growth studies whose samples include all three clubs. Indeed, it would have been a surprise if these dummies did not show up significantly.

Finally, since not all transitory paths of investment and output are smooth--in the regime-switching case there are kinks--it is not appropriate to use linearlization to approximate the transitory dynamics towards steady-state, as was previously done in the naive version of cross-country regressions which include regime-switching economies. In the regime-switching case, time series aspects of the convergence should be studied to test the out of steady state property. This will help us to gain a deeper understanding of the growth and development process in these economies.

The present model highlights the important role of the credit ceiling. Recall that creditors estimate the credit ceiling, B for a particular country based on their knowledge of the country's current and future productive wealth and their assessment of the efficiency of the domestic economy. How are these credit ceiling determined? How could one tell whether a particular economy is credit-constrained? These questions would have to be settled empirically. Chapter 7 will develop a Logit model to deal with these issues.

Our model also has policy implications. One of these is that for the poorest countries that are ever-constrained from international borrowing, initial levels of investment will be very low and insufficient, and convergence takes painfully long. For these countries to receive an initial push onto a sustainable growth path, aid from multinational organizations is critical.

Furthermore, any policy that reduces the domestic distortions and improves the efficiency of the economy should be pursued. In particular, eliminating distortions in the domestic credit market can serve double purposes for these countries. Not only can it generate domestic capital and investment, but it can also send positive signals to the country's creditors, improve their estimated creditworthiness, and upgrade the international credit constraint the country is facing. Similar arguments should prevail for advocating trade liberalization. For example, devaluation of an over-valued currency should improve competitiveness of a debtor country's exports industry, enhance its debt service capacity and also help to restore creditworthiness.

Chapter 6. Empirical Results

In this chapter, cross-country economic growth will be studied empirically, based on the three different growth models presented in previous chapters (in Chapters 2, 4, and 5). We do not impose the assumption that the economies are in the steady-state in any of the following specifications. Instead, we focus on growth performance on the transitory paths towards the steady-states: i.e., on out-of-steady-state dynamics.

The first model is the closed economy model of Chapter 2, the Solow model augmented to include human capital investment (MRW, 1992, and Barro, 1991). The original textbook Solow model can, of course, be obtained by imposing an appropriate zero restriction that specifies human capital share β as zero. In contrast, the other two models which have been studied in this thesis are both open economy growth models. They both examine growth under the assumption of imperfect capital mobility, but the ways in which they incorporate this notion are different from one another. The reformulated version of the BMS model, presented in Chapter 4, can be viewed as an augmented version of the MRW framework, with inclusions of newly identified openness and debt variables which were implicitly treated as omitted variables in the closed economy model. In this sense, the closed economy model is a special case of the BMS open economy model and can be obtained by applying appropriate exclusion restrictions to the BMS model. Recall that transitory dynamics in the BMS open economy model was given by (4.6):

$$\begin{aligned}\ln\frac{Y_t}{L_t}-\ln\frac{Y_0}{L_0} &= -(1-e^{-\lambda t})\left(\frac{\alpha+\beta}{1-\alpha-\beta}\right)\ln(n+g+\delta) \\ &\quad +(1-e^{-\lambda t})\left(\frac{\alpha}{1-\alpha-\beta}\right)\ln s_k+(1-e^{-\lambda t})\left(\frac{\beta}{1-\alpha-\beta}\right)\ln s_h \\ &\quad -(1-e^{-\lambda t})\ln\frac{Y_0}{L_0}+gt+(1-e^{-\lambda t})\ln A_0+\varpi\ln T\end{aligned} \tag{4.6}$$

The textbook Solow model is obtained from equation (4.6) by setting $\beta=\varpi=0$;[1] while the MRW augmented Solow model is obtained by setting $\varpi=0$. It is in this augmented Solow model context that we witness the significant regional dummies.

[1] Recall ϖ is defined in equation (4.5), $A_t=A_0e^{gt}T^{w}$.

As mentioned in previous chapters, given that the speed of convergence is positive in all three models under the general framework (4.6), the signs of the coefficients can be determined. The first term indicates that for a given set of α, β, δ, and g, per capita income growth is negatively related to population growth. The second term captures the role played by the capital investment in the process of economic growth. The more a country chooses to save and invest, the faster its economy grows. A similar analysis holds for the third term which applies to the saving and investment in accumulating human capital. It is the fourth term that indicates the "conditional convergence" hypothesis: ceteris paribus, a country grows faster per capita, if its initial income level is further below its steady state position (Mankiw et al., 1992, Barro, 1991, Levine and Renelt, 1992, and Barro and Lee, 1993). The next term, gt, simply reflects the time specific effect on growth as technology keeps on growing at a rate g. Still next term containing $\ln A_0$, represents all the unobserved (and unaccounted for) elements that determine the efficiency with which the productive factors and the available technology are used to create wealth. These are the only terms explicitly specified in the closed economy model. In addition to above terms, the BMS open economy model identifies a term that contains lnT, representing the degree of openness of a country. It is expected, everything else being equal, the more a country trades and competes with other countries in the world market, the more efficient it utilizes its resources in producing goods, and therefore the faster its economy grows. To apply the closed economy specification to a group of countries with varying degree of openness, amounts to treating any regularity associated with openness as cross country random shocks.

While the structural equation provided by (4.6) is general enough to encompass both cross-sectional and time series variations of growth, most empirical growth literature use (4.6) as a guideline but do not apply it literally, limited, in part, by the availability of time series data. Until recently, time series data covered by large scale international data sets were short and incomplete, so that most empirical growth studies to date employed cross-sectional data.

In cross-sectional growth studies, one can interpret (4.6) as a specification for a sample of different countries over a chosen time period, essentially regressing average growth rate during the period on average saving rates, average population growth, and so on. So there is one observation for each country. And since only one cross section is considered, the time-specific effects becomes irrelevant; gt term drops out. The dependent variable is the average growth rate over the period, independent variables are the average saving rates, etc. Notice that neither the value of g nor that for δ is specific to each country. g reflects primarily the advancement of general knowledge, which is not country-specific. As well, there is no strong reason to believe that capital depreciates at different rates in different countries. In essence we assume that, conditional on the other variables in the model, the exogenous rate of technological change and the rate of depreciation are equal across countries, and their sum is fixed at $g+\delta=0.05$.[2]

Specifically, to conduct cross sectional growth analysis over period 1960-1985, let time zero be 1960, and time t be 1985. Then the basic cross sectional estimating equation is as follows:

$$(6.1)\ \ln y_{85,i} - \ln y_{60,i} = \theta_0 + \theta_1 \ln y_{60,i} + \theta_2 \ln(n_i + 0.05) + \theta_3 \ln s_{k,i} + \theta_4 \ln s_{h,i} + \theta_5 \ln T_i + \theta_6 \ln D_i + \mu_i$$

where i is country index, μ_i is a random error term across country, and $\theta_1, \theta_2 \ldots \theta_6$ are parameters to be estimated. Comparing equation (6.1) with (4.6) makes it clear that for positive convergence parameter $\lambda>0$, θ_1, θ_2 and θ_6 are expected to be negative, while θ_3, θ_4 *and* θ_5, positive. Furthermore, the estimating parameters, θ_1 to θ_6 , are functions of structural parameters α, β, and λ. Therefore we can solve for implied structural parameters α, β, and λ from any set of estimated values of θ_1 to θ_6.

The error term in (6.1) comes from $\ln A_0$ term in (4.6). For instance, MRW specifies that

$$(6.2) \qquad \ln A_0 = a + \mu_i$$

where a is a constant, the common starting level of technology across all countries, and μ_i is a normally distributed, country specific, random shock for country *i*.

As MRW acknowledges, if countries have permanent differences in their production function, i.e. different A_0s, then these A_0s should enter as part of the error term and would be positively correlated with initial income. Hence, variation in A_0 would bias the coefficient on initial income downwards, against finding convergence. In order to use ordinary least square (OLS) to estimate the growth equation, MRW also assumes that A_0 is independent of the investment ratios and the growth rate of the population. This amounts to ignoring permanent country-specific effects (or *fixed effects* as called in econometrics): since the state of technology is the same in all countries except for random shocks, the innovative spill-over must be infinite and

[2] This assumption corresponds to the set of parameters cited in Chapter 2 and 4. The value for $g + \delta$ that is used in the estimation procedure is first used by MRW, and actually matches the available data.

instantaneous. As well, correlation between countries in terms of technological shocks is assumed away. Furthermore, this assumption implies that government policy regarding international trade, taxation, or external financing do not affect domestic investment.

Ideally, A_0 should represent all the unobserved (and unaccounted for) elements that determine the efficiency with which the productive factors and the available technology are used to create wealth. It suggests the presence of a country-specific effect, not independent of geographic, trade, institutions and so on, which may well be correlated with the other explanatory variables considered in the model.

One attempt to identify the unaccounted factors in A_0 is made by Barro (1991). Realizing the country-specific effect may be captured by continent-specific effects, Barro constructed two regional dummy variables, an African dummy and a Latin American dummy. The significantly negative estimated coefficients of both dummies, despite efforts to account for them by using political variables, lead him to conclude that "some regularities are missing from the (closed-economy) model" (Barro, 1991, p.435). In subsequent studies these dummy variables emerged time and again, along with a third, significantly positive regional dummy, East Asia. (See, for example, Barro and Lee, 1993). It is this empirical puzzle that we addressed in Chapters 4 and 5, using open economy growth models with imperfect capital mobility.

While our first open economy model in Chapter 4 can be regarded as a generalized case of MRW closed economy model, the other open economy model presented in Chapter 5 extends the empirical specification in a different way. Its theoretical results of kinked investment and output paths for regime-switching economies suggested that, when the sample includes regime-switching economies, treating saving/investment as an exogenous regressor is no longer an reasonable approximation, because of the presence of nonlinearity. Rather, investment itself also depends on population growth, initial income, openness and debt. Therefore, an appropriate econometric model should be a simultaneous equation system that consists of one growth equation and one investment equation. Since in this context, the endogenous variable investment, used as a regressor in the growth equation, is contemporaneously correlated with the disturbance term, the OLS estimates of the growth equation is biased, even asymptotically.[3] We present a two equation

[3] Kennedy, p. 151 and p.164. Recursive model is an exception of this general result.

system in detail in section 6.3, and use three stage least square (3SLS) estimator to get consistent and asymptotically efficient estimates of the model.

We will also consider an alternative specification for the BMS model in which panel data (rather than cross-sectional data) and a pooling technique (**SURE**) are employed to improve estimating efficiency.

6.1 Data and Samples

The data are from the Penn World Table (Mark 5), The World Debt Tables (The World Bank, 1993-1994 edition), and Mankiw, Romer and Weil (1992).[4] Detailed definitions and sources of the data for estimation are described in Appendix E. Two data sets are employed in this thesis, one cross sectional, the other pooled cross sectional-time series, and both are complied or combined from these three sources. Real income, population, investment, and openness variables are extracted from PWT5, debt variables and repayment information are from the World Debt Table, the human capital saving rate is taken from Mankiw, Romer, and Weil (1991),[5] the regional dummies for Africa (D1) and Latin America (D2) are constructed as in Barro (1991), and the regional dummy for East Asia (D3) is constructed according to the World Bank classification (World Bank, 1993).

Our sample covers a broad group of industrial and developing countries over the period 1960-1985. We consider two samples. The first one is comprehensive, including all countries for which data are available with the exception of major oil producers. The sample size is 98, one observation for each country. This sample is otherwise identical to MRW's non-oil producing sample of 98 countries, excluding Sierra Leone, Sudan and Burma, but including Iceland, Luxembourg and Malta. This is simply due to the availability of the data. The rationale for excluding the oil producers is that one should not expect standard growth models to account for

[4] For more information and a complete description of the data in the Penn World Table (Mark V) or PWT5, see Summers and Huston (1991). PWT5 presents in a variety of forms time series on expenditures of various sorts and on relative prices (that is, PPPs) covering nearly all countries of the world for an extended period. The latest publicly accessible version of this data sets contains 27 variables for the period 1950-1990 or part thereof, for 150 countries. This data base is accessible via INTERNET from NBER data base.
[5] This variable is termed as "SCHOOL" in Mankiw et al. (1992).

their recorded GDP, the bulk of which represents depletion of their natural resources. We follow their approach in order to make our results directly compatible to theirs.

Our second sample consists of 74 developing countries. This sample is of particular interest because, by definition, these countries, with their low initial incomes, should take advantage of the convergence effect. Yet the growth performances of these counties are highly divergent and, difference in investment, population and initial income variables have failed to account for this diversity. In particular, countries that are covered by three regional dummy variables all belong to this group of developing countries, but East Asian countries remarkably outperformed the others while African and Latin American countries significantly under-performed, compared to the sample average.

Each of the variables under consideration will now be explained in more detail. The dependent variable is the 25-year difference in the natural logarithm of real GDP per capita; that is $(\ln y_{85,i} - \ln y_{60,i})$. As noted above, the most general model includes six explanatory variables. The first is the natural logarithm of real GDP per capita, lagged one "period" (that is, 25 years back since the use of cross sectional data implicitly treats the whole time span under study as one period.)

The second explanatory variable is the natural logarithm of the average growth rate of population plus $(g+\delta)$; we follow MRW in assuming that $(g+\delta)=0.05$ for all countries. The third explanatory variable is the natural logarithm of the average ratio of real investment to real GDP. This average is also taken over the 25 years of the sampling period.

The fourth variable is a proxy for the saving rate for human capital investment. Human capital saving is measured as the percentage of working population that is enrolled in secondary school. Due to the lack of data exactly as defined above, MRW approximated it by the enrollment ratio out of the entire population that is eligible to be students, multiplied by the working age ratio. One can also argue that the enrollment ratio in primary school should be counted too, for the primary school education is a necessary investment to proceed to secondary education.[6] Still other authors prefer to use initial human capital stock rather than flow variables.[7] In any case, the measurement error associated with human capital variable is likely to be large.[8] Another potential problem is that adding the human capital variable is likely to create multicollinearity between this variable and investment and population growth, causing substantial changes of estimated coefficients of the latter two variables.

The fifth variable, ln T, is a proxy for the country's openness; it is the sum of exports and imports as a share of GDP. This proxy was used by Levine and Renelt (1992) and many of other papers that they surveyed. A country that has a large section involved in international trade will gain efficiency in diffusing new technology and the coefficient of this variable is expected to be positive.

Finally, D is the ratio of foreign debt to GDP averaged over the sampling period. D plays different roles in our two alternative, open economy models. In Model I, debt is not suppose to enter the growth equation directly. But trial-and-error regression suggests that its estimated coefficient is significantly negative. Theoretical results from Model II suggests that this may have been caused because, rather than affecting growth directly, debt affects investment, and therefore through investment affects growth indirectly. This is further confirmed by diagnostics tests.

6.2 Cross-Sectional Estimates for the Closed-Economy Model

We begin reporting our empirical results by duplicating the relevant previous empirical findings on unconditional and conditional convergence for cross-country growth, which are based on the closed economy model in Chapter 2, and are summarized by MRW (1992) and Barro (1991). This includes regressing the log difference of income per capita between 1985 to 1960 on the log of the initial income per capital in 1960, with and without controlling for investment, growth of population and school enrollment (MRW, 1992). Then we include regional dummies to recapture the unexplained regional disparity in the literature (Barro, 1991). In order

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[6] For example, Barro (1991) employs enrollment ratio in secondary school as well as that in primary school.

[7] Take, again, Barro (1991) as an example, where the enrollment ratios employed are ratios in the initial year, 1960, instead of the average ratios covering the entire period.

[8] However, only the constant term will be affected if SCHOOL is proportional to s_k.

TABLE 4
Tests For Unconditional Convergence
(Dependent variable: log difference GDP per capita, 1960-1985)

SAMPLE:	**All Countries**		**Developing Countries**
No. of Countries	**98**		**74**
VARIABLE	**COEFFICIENT (T-Ratio)**		**COEFFICIENT (T-Ratio)**
	Present Estimate	**MRW Result (3)**	**Present Estimate**
Constant	-0.5569	-0.266	-0.4071
	(-1.92)	(-0.70)	(-0.78)
$\ln y_{60}$ (1)	0.1406	0.0943	0.1150
	(3.79)	(1.90)	(1.54)
Implied λ (2)	-0.0053	-0.0036	-0.0044
	(-1.84)	(-1.64)	(1.51)
$\bar{R}^2$	0.07	0.03	0.01

Note: (1) Real GDP per capita lagged one "period" (that is , 25 years back).
(2) Speed of convergence, per year.
(3) Mankiw, Romer, and Weil (1992), Table III, pp.425.

to make comparisons easier, the original estimates of MRW and Barro were reprinted alongside with our present estimates whenever they are available.

In Table 4 the log of initial income per capita appears alone on the right-hand side, yielding results on the failure of *unconditional* income convergence. The coefficient on $\ln y_{60}$ is positive, for both the comprehensive and the developing country samples, and for both regressions the adjusted R^2 is virtually zero. This is consistent with MRW results for both their comprehensive and intermediate samples. *Unconditionally*, there is no tendency for poor countries to grow faster on average than rich countries.[9]

Next, we report estimates for the textbook Solow model. As indicated before, this specification can be obtained by imposing zero restrictions from the most general specification (6.1) by setting $\theta_4 = \theta_5 = \theta_6 = 0$; its corresponding regression equation is given by equation (6.1a).

[9] However, MRW does report a significant tendency toward unconditional convergence in their OECD sample, and interprets it as an indication of high proximity of thechnology and stage of development.

TABLE 5
Tests For Conditional Convergence in the Solow Model
(Dependent variable: log difference GDP per capita, 1960-1985)

SAMPLE:	**All Countries**		**Developing Countries**
No. of Countries	**98**		**74**
VARIABLE	**COEFFICIENT (T-Ratio)**		**COEFFICIENT (T-Ratio)**
	Present Estimate	**MRW Result (5)**	**Present Estimate**
Constant	-1.2377	1.93	-1.5990
	(-1.89)	(2.33)	(-0.98)
$\ln y_{60}$ (1)	-0.1398	-0.141	-0.0925
	(-2.66)	(-2.71)	(-1.420)
$\ln (n+0.05)$(2)	-0.5177	-0.299	-0.5467
	(-1.62)	(-0.98)	(-0.87)
$\ln s_k$ (3)	0.5044	0.647	0.4882
	(7.33)	(7.47)	(6.62)
Implied λ (4)	0.0060	0.0061	0.0040
	(3.31)	(3.33)	(2.19)
$\bar{R}^2$	0.43	0.38	0.36

Note: (1) Real GDP per capita lagged one "period" (that is , 25 years back).
(2) Average growth rate of the population, plus the sum of rates of technological progress and depreciation rate, $g+\delta=0.05$.
(3) Average ratio of real investment to real GDP.
(4) Speed of convergence, per year.
(5) Mankiw, Romer, and Weil (1992), Table IV, pp.426.

(6.1a) $$\ln y_{85,i} - \ln y_{60,i} = \theta_0 + \theta_1 \ln y_{60,i} + \theta_2 \ln(n_i + 0.05) + \theta_3 \ln s_{k,i} + \mu_i$$

Results for this specification are reported in Table 5. With the addition of measures of investment rates and population growth rate as explanatory variables, in both samples the coefficient on initial income $\ln y_{60}$ is now significantly negative;[10] that is, there is a strong tendency of convergence.

Moreover, the inclusion of these two new repressors improves substantially the fit of the regression. The adjusted R^2 is now 0.43 for our comprehensive sample and 0.36 our developing country sample. Our estimates of initial income ($\ln y_{60}$) and implied rate of

[10] Because heteroskedasticity could be important across countries, standard errors for all coefficients in this thesis are corrected by White's (1980) heteroskedasticity-consistent covariance matrix.

convergence (λ) are both remarkably close to those of MRW. And as in MRW, the implied rate of convergence is much smaller than value predicted by the textbook Solow model.[11] Given α=1/3, β=0 (no inclusion of human capital), n=0.02 and g+δ=0.05, the textbook Solow model predicts that λ=0.047, while the implied λ is 0.006 for the comprehensive sample and 0.004 (even smaller, only 1/10 of the predicted value!) for the developing country sample. This inconsistency between the data and textbook Solow model is even more striking in terms of half-time (e.g., the time required to move the economy half way to the steady state).[12] For the set of parameters given above, Solow model predicts that it will take the economy 15 years to move half way to the steady state, while the data implies that it will take 115 years on average for the 98 countries and even longer (173 years) for the developing countries.

Table 6 reports empirical estimates for the augmented Solow model by adding our measure of human capital as an extra regressor. Again, this model can be obtained by imposing zero restrictions from the most general specification (6.1) by setting $\theta_5 = \theta_6 = 0$; its corresponding estimating equation is given by equation (6.1b).

(6.1b) $$\ln y_{85,i} - \ln y_{60,i} = \theta_0 + \theta_1 \ln y_{60,i} + \theta_2 \ln(n_i + 0.05) + \theta_3 \ln s_{k,i} + \theta_4 \ln s_{h,i} + \mu_i$$

From Table 6, one can see that the new variable human capital investment further lowers the coefficient on the initial income, and it again improves the fit of the regression. The implied rate of convergence has now increased to around 0.013 (or 1.3% per year) for both samples, almost identical to MRW's estimate. In theory, the augmented Solow model predicts that the convergence rate is 0.023. This is lower than the textbook Solow model's prediction (0.047) because the total capital share is now (α+β) instead of just α so that diminishing returns set in more slowly. On balance, the gap between the predicted (by theory) and implied (by data) rate is much smaller than in the case of the textbook Solow model. The augmented Solow model is more consistent with the evidence than the simple Solow model, which shows how importance it is to account for human capital. Moreover, we test the restriction$\theta_2 + \theta_3 + \theta_4 = 0$ implied by

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[11] Recall, in theory, rate of convergence in the closed economy model with only physical (but not human) capital is given by (2.8); that is λ=(1-α-β)(n+g+δ) with β set to zero. The implied λ by the data can be obtained by solviing an equation linking structure parameters in (4.6) and estimated coefficients in (6.1a) by comparaing each terms. For example, to get λ (implied), set $\theta_1 = -(1 - e^{-\lambda t})$ and solve for λ.

[12] The formula for half-time (in number of years) is $T_{1/2} = (\ln 2) / \lambda$.

TABLE 6

Tests For Conditional Convergence in an Augmented Solow Model
(Dependent variable: log difference GDP per capita, 1960-1985)

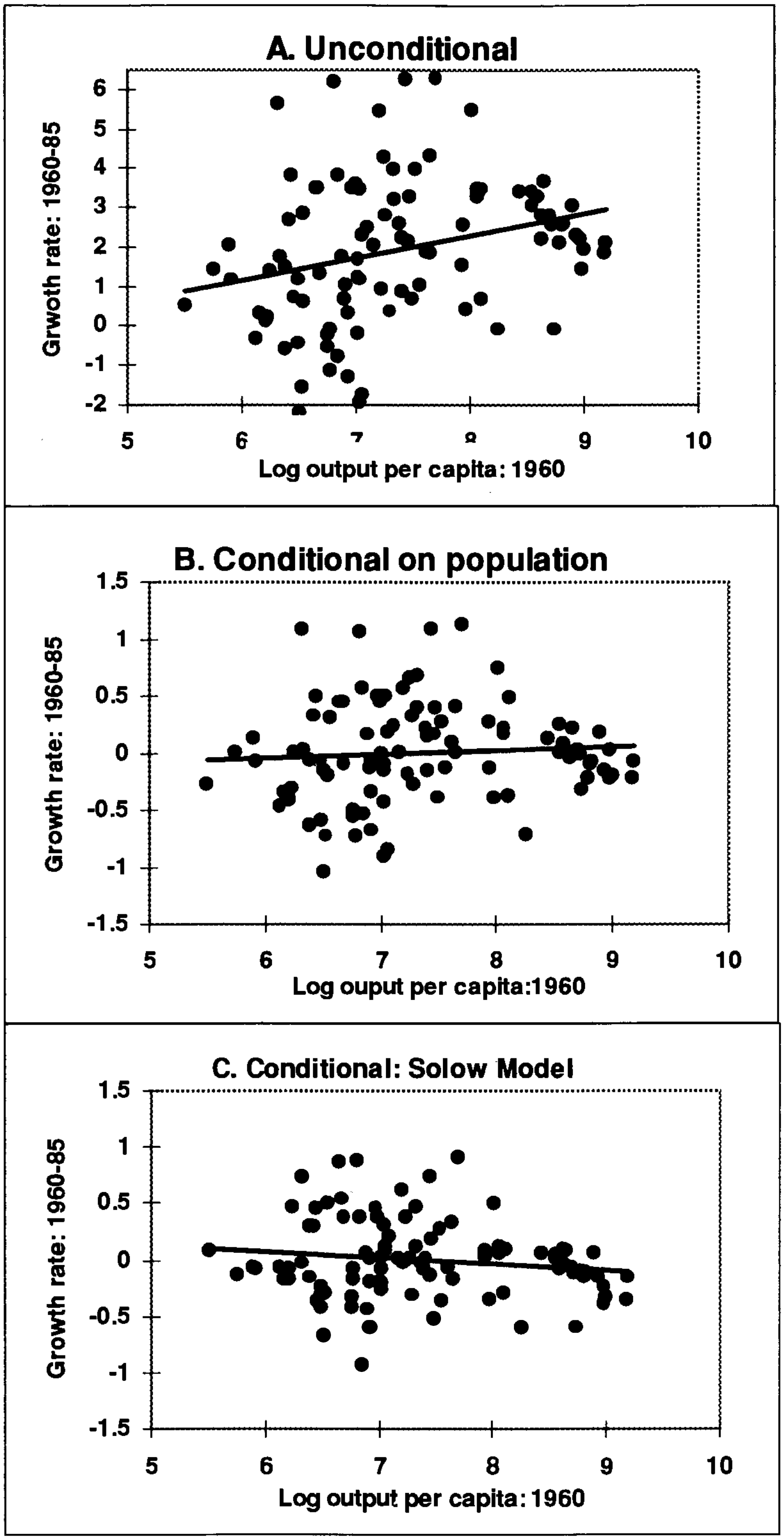
SAMPLE:	**All Countries**		**Developing Countries**
No. of Countries	**98**		**74**
VARIABLE	**COEFFICIENT (T-Ratio)**		**COEFFICIENT (T-Ratio)**
	Present Estimate	**MRW Result (6)**	**Present Estimate**
Constant	-0.6414	3.04	-0.0731
	(-1.17)	(3.66)	(-0.05)
$\ln y_{60}$ (1)	-0.2786	-0.289	-0.2820
	(-4.83)	(-4.66)	(-3.55)
ln $(n+0.05)$ (2)	-0.6909	-0.505	-0.4414
	(-2.49)	(-1.75)	(-0.79)
$\ln s_k$ (3)	0.3554	0.524	0.3309
	(5.59)	(6.02)	(4.60)
$\ln s_h$ (4)	0.2641	0.233	0.2714
	(4.56)	(3.88)	(4.36)
Implied λ (5)	0.0131	0.0137	0.0132
	(6.89)	(7.21)	(6.54)
F-test for $\theta_2+\theta_3+\theta_4=0$	0.05	n.a.	1.62
$\bar{R}^2$	0.54	0.46	0.47

Note: (1) Real GDP per capita lagged one "period" (that is , 25 years back).
(2) Average growth rate of the population, plus the sum of rates of technological progress and depreciation rate, $g+\delta=0.05$.
(3) Average ratio of real investment to real GDP.
(4) Ratio of human capital investment to GDP, proxies by the product of gross secondary-school enrollment ratio times the fraction of the working population aged 15 to 19.
(5) Speed of convergence, per year.
(6) Mankiw, Romer, and Weil (1992), Table V, pp.426.

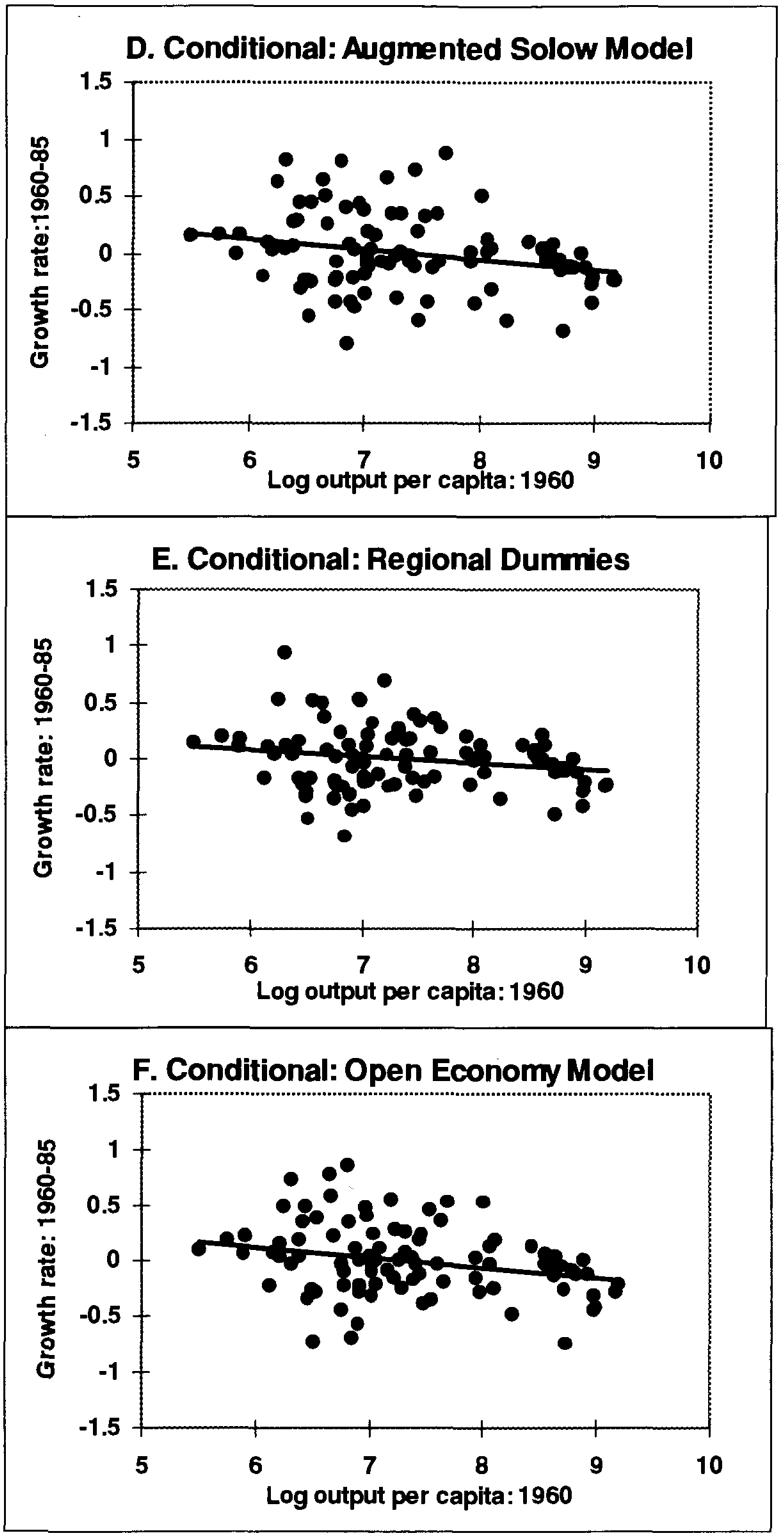
the Cobb-Douglas production in (6.2b). We found that the restriction is not rejected by the data for either sample, supporting the Cobb-Douglas form of production function.[13]

One can also demonstrate the effect of successively adding measures of population, accumulations of physical and then human capital graphically, in what has become known as "convergence picture" since Romer (1987). Figure 4 presents a generalized version of such a convergence picture. The slop of the line in each panel measures the correlation between the variables on two axis, the partial association. Panel A presents a scatterplot for our comprehensive sample of the average annual growth rate of income per capita from 1960 to 1985 against $\ln y_{60}$.

[13] $F_{0.01}(1,93)=6.85$ and $F_{0.01}(1,67)=7.04$.



A. Unconditional
Grwoth rate: 1960-85
6
5
4
3
2
1
0
-1
-2
5
6
9
10
Log output per capita: 1960
B. Conditional on population
Growth rate: 1960-85
1.5
1
0.5
0
-0.5
-1
-1.5
5
6
7
8
9
10
Log ouput per capita:1960
C. Conditional: Solow Model
Growth rate: 1960-85
1.5
1
0.5
0
-0.5
-1
-1.5
5
6
7
8
9
10
Log output per capita: 1960



Figuer 4. Convergence:
Partial Associations Between per Capita Growth and Initial Income

Obviously, there is no evidence that countries that start off poorer tend to grow faster. If anything, *unconditionally*, there is a slightly positive relationship between the growth rate and the initial income. Panel C plots the dependent variable, net of the value predicted by explanatory variables in the textbook Solow model except $\ln y_{60}$, versus $\ln y_{60}$. This partial association shows a negative slope of -0.1492. Panel D plot the similar partial correlation between the dependent variable and $\ln y_{60}$ for the augmented Solow model, adding the human capital to the list of variables that are being controlled. The tendency of convergence is now even stronger with a slope of -0.2410. These panels show that if countries did not vary in their investment and population growth rates, there would be a strong tendency for poor countries to grow faster than rich ones. Panel A, C, D, are equivalent to the three panels produced by MRW.[14]

In addition to MRW plots, Panel E is a plot when one adds regional dummies and panel F a plot when one adds additional controlling variables, openness and foreign debt. These two plots will be further discussed after studying corresponding regression results. Suffice is to notice here while adding dummies improves the fit of the regression, they do not help to support conditional convergence (slope = -0.19). In contrast, our open economy model is able to provide stronger evidence (slope = -0.27) over and on top of the augmented Solow model (slope = -0.24).

Table 7 presents estimates of equation (6.1b) imposing the restriction that the coefficient on $\ln s_k$, $\ln s_h$, and ln *(n+0.05)* sum to zero.[15] We do this in order to obtain the implied capital shares α and β in the Cobb-Douglas production function. We find the restriction is not rejected and that imposing it has little effect on the coefficients. Not unexpectedly, the estimate of α is lower for the developing country sample (0.37) than that for the comprehensive sample (0.40), but both are close to the value of 0.35 obtained by Maddison (1987) for the share of non-human

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[14] See, MRW Figure 1, p427. However, there are two differences between MRW plots and our plots here. First has to do with the fact that they partialed out ln(n+0,05), $\ln s_k$ and $\ln s_h$ from *both* sides of *dlny* and $\ln y_{60}$, while we partialed out these variables only from dependent variable side, e.g, plot the residuals from a partial regression exclusive of $\ln y_{60}$, vs. $\ln y_{60}$. The second difference is that MRW produced their plots using their intermediate sample (77) while we use our comprehensive sample (98) to get a fuller picture.

[15] This restriction is implied by the structural equation (4.6) on page 59.

TABLE 7
Augmented Solow Model, Restricted Regression
(Dependent variable: log difference GDP per capita, 1960-1985)

SAMPLE:	All Countries		Developing Countries
No. of Countries	98		74
VARIABLE	COEFFICIENT (T-Ratio)		COEFFICIENT (T-Ratio)
	Present Estimate	MRW Result (7)	Present Estimate
Constant	-0.5132	2.46	-0.3125
	(-2.06)	(0.48)	(-0.59)
$\ln y_{60}$ (1)	-0.2724	-0.299	-0.2857
	(-5.14)	(-4.90)	(-3.71)
$\ln s_k - \ln (n+0.05)$ (2)	0.3585	0.500	0.3315
	(6.07)	(6.09)	(4.66)
$\ln s_h - \ln (n+0.05)$ (3)	0.2636	0.238	0.2691
	(4.58)	(3.97)	(4.25)
Implied λ (4)	0.0127	0.0142	0.0135
	(7.86)	(7.47)	(6.35)
Implied α (5)	0.4008	0.48	0.3740
	(7.24)	(6.86)	(5.34)
Implied β (6)	0.2947	0.23	0.3036
	(5.27)	(4.60)	(5.62)
$\bar{R}^2$	0.55	0.46	0.48

Note: (1) Real GDP per capita lagged one "period" (that is , 25 years back).
(2) Average ratio of real investment to real GDP, net of Average growth rate of the population and the sum of rates of technological progress and depreciation rate, $g+\delta=0.05$.
(3) Ratio of human capital investment to GDP, proxied by the product of gross secondary-school enrollment ratio times the fraction of the working population aged 15 to 19, net of $g+\delta=0.05$.
(4) Speed of convergence, per year.
(5) Share of physical capital in the production function.
(6) Share of human capital in the production function.
(7) Mankiw, Romer, and Weil (1992), Table VI, pp.429.

capital in production. For both samples, the estimated share of human capital is around 0.30. Compared with our benchmark parameter values of $\alpha=\beta=1/3$, these regressions give a somewhat larger weight to physical capital and a somewhat smaller weight to human capital.

In order to detect permanent country-specific effects (*fixed* rather than *random effects* assumed under OLS), which, if correlated with initial income, biased the coefficient on $\ln y_{60}$ and therefore the rate of convergence, we proceed to run regressions of augmented Solow model with regional dummies for Africa (D1), Latin America (D2) and East Asia (D3) (Barro, 1991; Barro and Lee, 1993). The corresponding regression equation is given below.

(6.1c)

$$\ln y_{85,i} - \ln y_{60,i} = \theta_0 + \theta_1 \ln y_{60,i} + \theta_2 \ln(n_i + 0.05) + \theta_3 \ln s_{k,i} + \theta_4 \ln s_{h,i} + \gamma_1 D_1 + \gamma_2 D_2 + \gamma_3 D_3 + \mu_i$$

where γ_i is the coefficient for D_i, i=1,2,3.

Before reporting the estimation results for the above specification, in Table 8 we present the summary statistics of the average growth of real per capita income over 1960-85 for different regions. This table tells the story that is masked behind the statistical significance of regional dummies for Africa, Latin America, and East Asia. The upshot is that average growth rate in Africa (0.2%) and in Latin America (1.5%) is systematically lower than the sample mean (2%), while that of East Asia (5%) is systematically and substantially higher. Interestingly, the sheer number of underachievers more than offsets the lifting effect of spectacular but few star performers, resulting a developing country average (1.6%) that is slightly lower than total sample mean (2%). The question is, are the differences in population growth, and rates of accumulation for physical and human capital as suggested by the augmented Solow model sufficient to explain the difference in growth rate across the countries in different regions? The answer, according to the regressions results in Table 9, is no.

TABLE 8
Summary Statistics of Real Per Capita Growth Rate, Averaged over 1960-85
(In percentage for different regional groups)

GROUPS	NO. OF COUNTRIES	MEAN	ST. DEV.	MIN.	MAX.
All Countries	98	1.91	1.83	-2.22	6.29
Developing Countries	74	1.58	1.93	-2.22	6.29
African, D1	32	0.19	1.82	-2.22	5.62
Latin American, D2	21	1.45	1.09	-1.52	3.64
East Asian, D3	7	5.16	1.15	3.82	6.29

TABLE 9

Tests For Regional Dummies in an Augmented Solow Model

(Dependent variable: log difference GDP per capita, 1960-1985)

SAMPLE:	**All Countries**		**Developing Countries**
No. of Countries	**98**		**74**
VARIABLE	**COEFFICIENT (T-Ratio)**		**COEFFICIENT (T-Ratio)**
	Present Estimate	**Barro's Result (6)**	**Present Estimate**
Constant	0.3144		0.7204
	(0.50)		(0.52)
$\ln y_{60}$ (1)	-0.2068	-0.175	-0.1814
	(-3.76)	(-7.7)	(-2.69)
$\ln (n+0.05)$ (2)	-0.2869	n.a.(7)	-0.0746
	(-0.99)		(-0.02)
$\ln s_k$ (3)	0.2801	n.a.(8)	0.2669
	(4.58)		(3.87)
$\ln s_h$ (4)	0.1857	n.a.(9)	0.1818
	(3.30)		(3.04)
D1 (Africa)	-0.2434	-0.26	-0.2408
	(-2.15)	(-2.97)	(-2.09)
D2 (Latin America)	-0.2383	-0.26	-0.2391
	(-3.04)	(-3.71)	(-2.86)
D3 (East Asia)	0.4544	n.a.	0.4714
	(4.26)		(3.54)
Implied λ (5)	0.0093	0.0077	0.0080
$\bar{R}^2$	0.66	0.66 (10)	0.61

Note: (1) Real GDP per capita lagged one "period" (that is , 25 years back). This involves converting between two dependent variables since Barro used different units.

(2) Average growth rate of the population, plus the sum of rates of technological progress and depreciation rate, $g+\delta=0.05$.

(3) Average ratio of real investment to real GDP.

(4) Ratio of human capital investment to GDP, proxied by the product of gross secondary-school enrollment ratio times the fraction of the working population aged 15 to 19.

(5) Speed of convergence, per year.

(6) Barro (1991), Table IV, regression 29, pp.429.

(7) Fertility was treated as an dependent variable instead.

(8) When stock variable is used, as is in Barro (1991), the expected coefficients have different magnitude, except for lny60 term.

(9) Reason as given in (8). Also desegregated measures of human capital stock are used, such as enrollment ratio for male and female.

(10) This also includes contributions of other explanatory variables used by Barro (1991), such as government consumption and fertility rate.

Table 9 presents the estimation including regional dummies. In both samples, the African and Latin American dummies are significantly negative, and the East Asian dummy is significantly positive; there are substantial region-specific effects unexplained by the variables in the augmented Solow model.

While dummies indicate unexplained regularities, they themselves are not explanations, nor are they remedies for the fact that the implied λ is smaller than the value predicted by the augmented Solow model. In fact, when dummies are included, the implied λ is even smaller (0.009 instead of 0.013). This is so because all three dummies are negatively correlated with initial income, and further bias its coefficient toward zero. The clarify this point, it helps to take another look at Figure 4. In panel E, although the points scatted more tightly around the partial association line, convergence effects that is measured by the slope of that line is smaller in absolute value (-0.1998) than in case of the Solow model (panel D, slope=-0.241). Panel E is essentially the same plot presented by Barro (1991); his right-hand variables also include regional dummies.[16]

Also notice that, in both samples, the inclusion of regional dummies changes the coefficient of population growth a great deal and makes that coefficient insignificant. This change is due to the correlation between the dummies and population growth.

Before leaving the estimations for the closed economy models, we perform a series of diagnostic tests on the OLS estimates of the augmented Solow model, in an attempt to detect any inadequacy in specification. In particular, our concerns are (1) Is there any serious econometric problem associated with our estimation, given the data? (2) If yes, what are the causes of the problem(s)? Is it due to plain cross-sectional heteroskedasticity that is common for cross-sectional data or as a result of a more fundamental misspecification: omission of unknown

[16] However, there are two differences between Barro's plot and panel E in our Figure 4. The first has to do with the unit of horizontal axis. Barro used y_{60} (in $1,000), while we used $\ln y_{60}$ as in MRW. Secondly, his regression includes at least four additional variables ranging from government spending to political assissination, making it difficult to assess its *quantative* value of partial association.

variables, or nonlinearity, or incorrect function form? (3) If the problem is decided to be one of misspecified model, how should we respecify the model with the guidance of the theory?

RESET specification tests yields a F statistic of 4.07 that exceeds the critical value of $F_{0.05}(1,92) = 3.92$ at the 95% confidence level, suggesting either unknown variables have been omitted or wrong functional form has been used. On the other hand, heteroskedasticity test yields a high χ^2 value of 30.2, which far exceeds the critical value, $\chi^2_{0.05}(4)=14.86$. The second test seems to suggests plain heteroskedasticity. Thursby (1982) develops a methodology to discriminate between heteroscadasticity and misspecification. According to Thursby, misspecification can be picked up by the heteroskedasticity test. But if both RESET and Chow tests are significant, as they are in this case, then the diagnosis should be misspecification rather than heteroskedasticity.

Once the problem is determined to be misspecification, we proceed to explore the avenues to respecify the augmented Solow model. Our open economy models suggests the first respecification: to include previously omitted open economy variables, openness and foreign debt, into the regression equation.

The second respecification is more complicated. Our second open economy in Chapter 5 suggests that investment, which appears as a regressor in the growth equation, is itself endogenous in open economy with imperfect capital mobility and is simultaneously determined with growth. When an endogenous variable is used as a regressor, the classical linear regression assumption of stochastic independent variables is violated. An endogenous variable cannot be considered fixed in repeated samples. A simultaneous system of equations will result in contemporaneous correlation between the endogenous variable serving as a regressor and the error term. OLS estimates are biased in this situation. Herein lies the importance in determining empirically the endogeneity/exogeneity of the investment variable. A Hausman test for

Endogeneity allows us to reject the null hypothesis that investment is exogenous. The test statistic is a T-test with a value of 3.017.[17]

The Hausman test confirms what is suggested by our second open economy model. The model should be respecified as an system of two simultaneous equations with one growth equation and one investment equation.

6.3 Cross-Sectional Estimates for the Open-Economy Models

Our first open economy specification is the most general specification in (6.1) without imposing any zero restrictions.

$$(6.1)\ \ln y_{85,i} - \ln y_{60,i} = \theta_0 + \theta_1 \ln y_{60,i} + \theta_2 \ln(n_i + 0.05) + \theta_3 \ln s_{k,i} + \theta_4 \ln s_{h,i} + \theta_5 \ln T_i + \theta_6 \ln D_i + \mu_i$$

The estimating results for this specification are reported in Table 10. As expected, coefficient of openness variable is positive and that of foreign debt is negative, and both are significant. As in the regression with dummy variables, the coefficient on population growth becomes insignificant, reflecting correlation between explanatory variables. But unlike dummy variables, open economy variables further lowers the coefficient on initial income, helping to narrow the gap between the predicted and implied rate of convergence. This is shown more clearly in Panel D and F of Figure 4. The partial association becomes more negative as a result of adding open economy variables (the slope changes from -0.21 to -0.27).

[17] The Hausman test is performed in the following fashion. First, regress investment on all exogenous variables, get predicted value of investment from this regression. Second, use the predicted value of investment as an instrumental variable, and run the growth equation with *invement* and *the instrument of investment* both included. A significant t-value on the instrument will mean that in addition to the direct impect of investment on growth, there is also a significant indirect impect of investment on growth, therefore investment is itself endogeous.

TABLE 10
Tests For Convergence: Open Economy Model
(Dependent variable: log difference GDP per capita, 1960-1985)

SAMPLE: **No. of Countries** **VARIABLE**	**All Countries** **98** **COEFFICIENT** **(T-Ratio)**	**Developing Countries** **74** **COEFFICIENT** **(T-Ratio)**
Constant	0.8778	1.5300
	(1.16)	(1.18)
ln y_{60} (1)	-0.3021	-0.2855
	(-5.21)	(-3.74)
ln $(n+0.05)$ (2)	-0.2361	0.0454
	(-0.74)	(0.09)
ln s_k (3)	0.3161	0.2813
	(4.91)	(3.866)
ln s_h (4)	0.2892	0.2884
	(5.18)	(4.59)
Open (5)	0.0016	0.0023
	(2.04)	(2.21)
Debt (6)	-0.0048	-0.0047
	(-3.23)	(-3.21)
Implied λ (7)	0.0144	0.0134
$\bar{R}^2$	0.61	0.56

Note: (1) Real GDP per capita lagged one "period" (that is , 25 years back).
(2) Average growth rate of the population, plus the sum of rates of technological progress and depreciation rate, $g+\delta=0.05$.
(3) Average ratio of real investment to real GDP.
(4) Ratio of human capital investment to GDP, proxied by the product of gross secondary-school enrollment ratio times the fraction of the working population aged 15 to 19.
(5) Average share of exports and imports of real GDP.
(6) Ratio of total debt outstanding to real GDP.
(7) Speed of convergence, per year.

Table 11 summarizes estimating results for our second open economy specification: a system to simultaneous equations, one for growth rate and one for investment. The model is specified as below (6.2):

(a) $\ln y_{85,i} - \ln y_{60,i} = \theta_0 + \theta_1 \ln y_{60,i} + \theta_2 \ln(n_i + 0.05) + \theta_3 \ln s_{k,i} + \theta_4 \ln s_{h,i} + \theta_5 \ln T_i + \theta_6 \ln D_i + \mu_i$

(b) $\ln s_{k,i} = \rho_1 \ln T_i + \rho_2 \ln D_i + \rho_3 \ln g_i + \varepsilon_i$

where g is the share of government consumption in GDP.

The specification of investment equation is somewhat crude and deserves further explanation. Here, we are mainly interested in the variations in investment caused by the variations in open economy variables, and have not include other domestic variables that are potentially important. Openness is expected to facilitate and promote physical capital investment (Levine and Renelt, 1992). The term of foreign debt is supposed to capture the effect that is addressed in the debt literature: excessive foreign borrowing, acting as a tax, creates disincentive to invest. The term of government consumption, g, measures the domestic tax burden borne by the private sector. Both these terms, foreign debt and government consumption, can potentially "crowd out" private investment (Cohen, 1993).

This two-equation system is estimated with 3SLS so the estimates in Table 11 are consistent and asymptotically efficient. As can be read from Table 11, all estimated coefficients are significant with the expected signs. One exception is again the population variable that is not significant. In the first equation, the weight of physical capital is much higher than previous OLS estimates, and the implied rate of convergence increases to 0.016 from the last OLS estimate 0.0144. In the second equation, coefficient on foreign debt is negative, lending support to the "debt Laffer curve" hypothesis (Krugman, 1988). Moreover, openness has a positive effect on investment, reconfirm the robust "two-link" chain identified by Levine and Renelt (1992). Finally, government consumption is negatively associated with investment, indicating a "crowding-out" effect.

TABLE 11
Simultaneous Equation Estimates (I): Open Economy Model
(For the Comprehensive Sample with 98 countries)

Equation 1
Dependent variable: Log Difference in GDP per capita, 1960-1985

VARIABLE	COEFFICIENT (T-Ratio)
$\ln y_{60}$	-0.3307 (-4.46)
$\ln (n+0.05)$	-0.5753 (-1.53)
$\ln s_k$	0.5747 (2.06)
$\ln s_h$	0.3369 (2.83)
Implied λ	0.016

Equation 2
$$\ln s_{k,i} = \rho_1 \ln T_i + \rho_2 \ln D_i + \rho_3 \ln g_i + \varepsilon_i$$

VARIABLE	COEFFICIENT (T-Ratio)
$\ln T$ (Open)	0.2878 (3.02)
$\ln D$ (Debt)	-0.1294 (-3.46)
$\ln g$ (Government)	-0.522 (-3.58)
$\bar{R}^2$ (system)	0.522

6.4 Pooled Cross-Sectional and Time Series Estimates

Up to this point, all our empirical results are obtained employing cross-sectional data, as is most comment in the empirical growth literature. As we have acknowledged, using cross-sectional data forced the use of some restrictive assumptions in econometric specifications, and there are several disadvantages associated with that. First, since only one cross section is considered for each country, any dynamic variation over time within a country is ignored; there is no way to accommodate short-run persistence or autocorrelated errors over time. Secondly, for a group of countries, the error terms in the growth equation certainly includes factors that are common to all the countries, such as global recession or oil price hikes at any given time, as well as factors that are specific to each country. Considerable efficiency is gained by estimating the equations jointly. Finally, averaging over a period of time drastically reduces the amount of information contained in the data.

While panel data approach and its rich resources of econometric techniques are gathering momentum in other areas such as labor economics and finance, it has yet to make its mark in empirical growth literature. Part of the problem is the data. Until recently, time series data covered by large scale international data set were short and incomplete. Even today, not all variables used in this thesis are available in time series form. For example, there is no time series data for any measure of human capital. Time series data on foreign debt variables only became available last year, and they only cover 71 developing countries from 1970 onward. While these limitations preclude any serious pursuit of the panel data approach at this stage, we will nonetheless present some preliminary results, employing seemingly unrelated regression estimation (SURE). Our purpose is to demonstrate potential efficiency gains, and to warn against possible problems. Since a key variable, human capital, is not included in our pooled data set, we will not interpret or evaluate the values of coefficient.

Table 2 presents reestimation of our simultaneous equation system with the available panel data set. It covers 71 developing countries for 21 years. When missing data points are skipped, there are 1341 observations. We include the cross-sectional, 3SLS estimates in the last section alongside but we warn that the two sets of coefficients are not comparable. Our purpose is to make some general observations about the panel data approach, using this exercise as an example.

TABLE 12
Simultaneous Equation Estimate (II): Open Economy Model

Equation 1
Dependent variable: Log Difference in GDP per capita, 1960-1985

VARIABLE	COEFFICIENT (T-Ratio) 3SLS Estimates (98 obs.)	SURE Estimates (1341 obs.)
$\ln y_{t-1}$	-0.3307	-0.8583
	(-4.46)	(-94.19)
$\ln (n+0.05)$	-0.5753	-0.0399
	(-1.53)	(-3.44)
$\ln s_k$	0.5747	0.6350
	(2.06)	(26.43)
$\ln s_h$	0.3369	n.a.
	(2.83)	
Implied λ	0.016	0.078

Equation 2

$$\ln s_{k,i} = \rho_1 \ln T_i + \rho_2 \ln D_i + \rho_3 \ln g_i + \varepsilon_i$$

VARIABLE	COEFFICIENT (T-Ratio) 3SLS Estimates (98 obs.)	SURE Estimates (1341 obs.)
$\ln T$ (Open)	0.2878	0.3563
	(3.02)	(11.45)
$\ln D$ (Debt)	-0.1294	-0.0145
	(-3.46)	(-3.71)
$\ln g$ (Government)	-0.522	-0.7350
	(-3.58)	(-17.23)
$\bar{R}^2$ (system)	0.52	0.86

Note: sample size for 3SLS estimates is 98 countries. For SURE estimates, the dimensions of the panel is 71 countries by 21 years (1970-1990), resulting 1341 observations in total after skipping missing observations.

Although its two columns are not to be compared directly, Table 12 reveals some properties of the panel data approach in general and the SURE estimating procedure in particular; most obviously, the huge gain in efficiency, as indicated by high t-values. Under the same model, panel data using SURE produces a much better fit ($\overline{R}^2$ =0.86) than fit using cross-sectional data ($\overline{R}^2$ =0.52). Moreover, the estimated coefficients change substantially. This is so because SURE allows for different countries' random effects to be correlated over time; this was previously unaccounted for. But SURE is still rather restrictive. An better alternative, that would allow full variation over time and across countries, would be a more general error component model, breaking the error term into a time-specific error η_t, a country-specific error μ_i,, and a pure random error $\varepsilon_{i,t}$ associated with each specific observation. This alternative is beyond the scope of this thesis. Hopefully in the future, as the quality and coverage of data improves, the fuller use of panel data will help to deepen our understanding of the economic growth process.

Chapter 7 A Logit Model to Predict the Probability of Being Credit-Constrained

This thesis has studied, both theoretically and empirically, the economic growth of an open economy with imperfect capital mobility. We have shown in chapters 4 and 5 that, in this international borrowing environment, the growth property of a small debtor country depends critically on whether the economy is being credit-constrained. For example, in the model in Chapter 5, the growth and investment paths of a country exhibit kinks when an economy switches from a credit-unconstrained regime to a credit-constrained one. So, to understand the growth process of such an economy, it is important to understand the determination of its credit ceiling.

Several determining variables are suggested in theory. In BMS, the credit ceiling is assumed to be identical to the country's existing stock of physical capital. Other writers assume it to be a fraction of physical capital (Cohen and Sachs, 1984) or income. Yet others hypothesize that credit ceiling should be equal to the value of tradable goods since export earning is a good indicator of debt service capacity. Finally, since a large fraction of developing country debt is guaranteed by the debtor government, credit ceilings are limited by the government's financing capacity, which is in practice much smaller than capital stock.

In practice, a credit ceiling also depends on many more factors other than the borrowing country's capital or output of any measure. These include factors that are beyond the strategic interaction of an individual borrower and its lenders, and factors that are not necessarily related to its solvency. Rather, historical episodes of international financial crises generally affect the creditworthiness of borrowers as a group. To make the matter more complicated, a credit ceiling is not directly observable, and can be inferred only implicitly when the country becomes credit-constrained, which is observable in the international loan market. So in the end, the issue has to be settled empirically.

In this chapter, we develop and estimate a Logit model to predict the probability of a country's being credit-constrained. A Logit model is a multivariate regression analysis technique which is used primarily to make predictions in dichotomous situations. Once a logistic function has been estimated from historical data, new data can be substituted into the function to estimate the current probability that a country will be credit-constrained. Such a model is commonly employed in the empirical debt literature to study factors that affect the external debt serving capacity (Ngassam, 1991), and to predict debt arrears (Li, 1992) and rescheduling (Backer, 1992) of particular group of countries. We introduce this model to the growth literature in the hope that it will shed light on the complex factors and relationships behind the unique growth path of a credit-constrained economy.

The proxy for being credit-constrained is the incidence of debt rescheduling. In fact, explicit credit constraints are often observed in debt rescheduling contracts. Debt rescheduling is an extension or stretching out of the original repayments schedule. It usually comes with some restrictions on the volume of future borrowings over a specified numbers of years.

7.1 Model Specification

We assume the probability of being credit-constrained is given by

(7.1a) $$P_i = \frac{1}{1+e^{-(a+bX_i)}}$$

where the variables and parameters are defined as follows:

- P_i: probability of being credit-constrained
- X_i: a vector of explanatory variables
- b: a vector of coefficients.

Then the probability of not being credit-constrained is

(7.1b) $$1-P_i = \frac{1}{1+e^{(a+bX_i)}}.$$

While the dependent variable, the probability P_i, is itself unobservable, the measured dependent variable Y_i is observable, with Y_i=1 if a country has rescheduled its debt in that year and Y_i=0 if it has not. Our objective is to find parameter estimates of $\boldsymbol{a}$ and $\boldsymbol{b}$. Maximum likelihood estimators, which are consistent, asymptotically efficient and normal, are the most suitable in a Logit model like this.

Suppose a sample consists of N observations. For m of these observations a rescheduling is recorded (Y_i=1), and for the remaining N-m (Y_i=0). The maximum likelihood function that we wish to maximize has the following form

$$
\begin{aligned}
L &= \Pr(Y_{1,}Y_2 \ldots Y_N) = \Pr(Y_1)\Pr(Y_2)\ldots\Pr(Y_N) \\
&= P_1 \ldots P_m (1-P_{m+1})\ldots(1-P_N) \\
&= \prod_{i=1}^{m} P_i \prod_{j=m+1}^{N} (1-P_j)
\end{aligned}
\tag{7.2}
$$

Substituting (7.1a) and (7.1b) into (7.2) and taking the log of the resulting equation, we get the log maximum likelihood function

$$
\ln L = -\sum_{i=1}^{m} \ln(1+e^{-(a+bX_i)}) - \sum_{j=m+1}^{N} \ln(1+e^{(a+bX_j)})
\tag{7.3}
$$

Partially differentiating $\ln L$ with respect to ***a*** and ***b*** and setting the resulting equations to zeros, one can obtain the slope estimators of ***a*** and ***b***. This maximization is accomplished by a nonlinear maximization procedure in SHAZAM.

The explanatory variables in vector X include three groups: traditional macroeconomic variables that measure the fundamental *creditworthiness* of a country in the long run, balance sheet ratios that reflect a country's *ability* to service its debt in the short run, and aggregate global economic indicators that affects a country's *willingness* to pay for a given global attitude toward rescheduling, current credit possibilities, and average cost of borrowing.[1] We now discuss these variables in more detail.

---

[1] For more explanations, see Backer (1992).

(1) Debt service ratio, defined as the ratio of debt service payment to exports. The higher the ratio, the greater will be the likelihood that, in the event of a severe decline in export earnings, the country will no longer be able to meet debt service obligations. The probability that a country will seek a rescheduling rises as its debt service ratio rises.

(2) Reserves to imports ratio relates a country's foreign reserve levels to its potential needs for reserves. When reserves are high, it is likely that export shortfalls can be met through drawdowns of reserves. The higher the ratio of foreign reserves to imports, the lower will be the probability of rescheduling.

(3) Ratio of debt service to capital inflow. Capital inflows in the forms of loans, grants, direct foreign investments, and transfer payments are important sources of foreign exchange receipts which can be used for debt service. As this ratio increases, a country's ability to meet debt service obligations declines.

(4) GDP growth rate measures a country's potential wealth, productivity and return on investment. The probability of rescheduling is negatively related to the debtor country's rate of economic growth.

(5) Investment to GDP ratio raises the productive capacity of the economy and increases the amount of resources available to service the debt in the future. The probability of rescheduling should have a negative association with investment share.

(6) Last but not the least, the average interest rate at which a country borrows reflect the burden of debt service. A sharp rise in interest rate will increase every country's probability of rescheduling across board.

In the next section, we will use these variables as the set of explanatory variables to estimate the probability of rescheduling in the Logic model developed in this section. To avoid the simultaneity problem between the dependent variable, income growth and investment share, we use the lagged values for these two variables instead of concurrent values.

7.2 Empirical Results

To apply the Logit model to the estimation of rescheduling probabilities (which is a proxy for a country being credit-constrained), we complied annual data for 71 developing countries over the period 1970 to 1990. The data source is the World Bank Debt Tables (mostly 1994 edition, and occasionally previous editions). Potentially, there are 1491 observations in the sample (71 countries by 21 years). After observations with missing data were skipped, the actual sample consists of 1317 observations. There are 302 observations of rescheduling (Y_i=1) and 1015 observations of nonrescheduling (Y_i=0).

Results of the estimation of the Logit model of rescheduling appear in Table 13. The variables in the table refer, respectively, to the debt service ratio, the ratio of reserves to imports, the debt service payments to capital inflow ratio, the lagged GDP growth rate, the lagged investment to GDP ratio, and the average rate of interest on loans. The estimated results broadly confirm the hypothesized influences on debt rescheduling and succeed to a relatively high degree in explaining rescheduling and nonrescheduling. The percentage of correct prediction is 79%; using explanatory variables as a set, the logit model is capable of identifying whether or not a country has rescheduled its debt (and therefore is credit constrained) with about 80 percent accuracy. This success rate compares favorably with that obtained in previous studies of this nature.

The debt service ratio is significant and has the correct sign: The probability that a country will reschedule its debt increases as its debt service ratio increases. The same is true of the reserves to imports ratio, which has the expected negative sign (higher reserves mean lower likelihood of rescheduling). The debt service to capital inflow ratio has a wrong sign and its is not significant. Given the success of this variable in similar models (for example, Ngassam, 1992), this is puzzling.

TABLE 13

Estimates of Logit Model of Debt Rescheduling
(Dependent variable: Probability of rescheduling)
(Pooled data for 71 countries during 1970-1990; sample size: 1317)

VARIABLE	**COEFFICIENT (T-Ratio)**(3)
Debt Service Ratio	0.0026 (6.24)
Reserves to Imports Ratio	-0.0588 (-2.05)
Debt Service to Capital Inflow Ratio	-0.0002 (-0.43)
GDP Growth Rate (1)	-0.2900 (-3.81)
Investment Share in GDP (2)	-0.0698 (-5.77)
Average Interest Rate on Loans	0.1215 (4.34)
Constant	-1.0813 (-5.098)
Rate of Right Predictions	0.7952

Note: (1) Lagged one year.
(2) Lagged one year.
(3) These are asymptotic estimates and T-ratios from a non-linear estimating procedure in SHAZAM.

One possibility is that of multicollinearity between this variable and other explanatory variables, but this conjecture is denied by inspecting the correlation matrix of the variables. Since this variable was constructed from several other variables, serious measurement problems may be suspected. The GDP growth rate and investment share also have the correct signs and are significant (the higher the country's growth rate or investment, the lower its probability of rescheduling). And finally, the average interest rate on loans has the appropriate positive sign, and is significant. In the light of dramatic increases in interest rates in international loan markets in the early 1980s and subsequent drastic increases in incidences of developing country debt rescheduling, this last result is highly expected. Higher interest rates mean a heavier burden of debt and therefore a higher probability of rescheduling.

In summary, on the basis of statistical tests, the Logit model estimates indicate that debt-service ratio, reserves to imports ratio, GDP growth rate, investment share in GDP, and average interest rate on loans are important indicators of debt service capacity. For a given country, a predicated value of close to one indicates that it is highly likely that the country is being credit constrained in international loan markets.

Chapter 8 Conclusion

This thesis has extended both the theoretical and empirical frameworks of recent literature on cross-country growth from a closed-economy to an open-economy setting, under the assumption of imperfect capital mobility.

The closed-economy Solow model, when augmented to include human capital accumulation, predicts that differences in saving, education and population growth should explain cross-country differences in income per capita. In contrast to "endogenous" growth models, which assume constant or increasing returns to reproducible factors of production, the augmented Solow model implies that countries with similar technologies, rates of capital accumulation and population growth should converge in income per capita because diminishing returns set in eventually. While this convergence prediction has been supported by recent empirical growth studies (Mankiw, Romer and Weil, 1992 (MRW); Barro ,1991; Levine and Renelt, 1992), the closed-economy model has failed to answer the following questions: (1) Why do the variables taken to be exogenous in the augmented Solow model vary so much from country to country? (2) What are the plausible explanations for Baumol's hypothesis that convergence occurs within three "growth clubs", rather than among them (Baumol, 1987)? (3) What are the "missing regularities" from the closed-economy model that would explain the empirical puzzle that African and Latin American countries have been growing systematically slower than the sample mean while East Asian countries have been growing systematically faster (Barro, 1991; Barro and Lee, 1993)?

Obviously missing from the closed economy model are open economy variables such as trade and foreign debt. This suggests extending the analytical framework to an open economy setting. While a small open economy model with perfect capital mobility (Blanchard and Fisher 1989, Ch.2.4) can accommodate foreign debt and trade in the steady state, it fails to generate economically meaningful transitory dynamics outside the steady state. Specifically, the assumption of perfect capital mobility means that a small open economy will jump to its steady state instantaneously by borrowing or lending as much as it needs to reduce the domestic marginal product of capital to the world interest rate. Therefore its implied speed of convergence is infinite. In short, the open economy model with perfect capital mobility fails to accommodate the empirical reality that the convergence is gradual.

Unrelated theoretical models exist in the debt literature. These attempt to address growth issues in an open economy which faces imperfect international capital markets. For example, Barro, Mankiw and Sala-i-Martin (1992) (BMS) distinguishes the asymmetric roles played by physical and human capital as collateral. Isgut (1993) studies a debtor country's growth path when it faces an exogenous credit constraint in the international loan markets. Working under alternative assumptions regarding the specific form of imperfect capital mobility, both models overcome the theoretical deficiency associated with perfect capital mobility, generating more realistic and gradual convergence paths outside the steady state. These models are consistent with the slow growth experience of African and Latin American countries. However, prior to this thesis, none of them have been empirically tested, nor had they been applied to cross-country growth.

The "export-led" growth literature has long credited the East Asian countries' remarkable growth records to their outward-orientated trade polices, but their models have not been cast in the framework of the cross-country growth literature. Finally, some of the literature has reported empirical evidence supporting foreign debt and current account conditions as determining factors of growth, mostly on an *ad hoc* basis.

This thesis has attempted to link all the previously unrelated literature in a more general open economy growth framework, in order to address unexplained regional growth disparities in cross-country growth. First, we establish a model that is general enough to encompass the closed economy model and the open economy model with perfect capital mobility as two special cases. When restricted, our model enables us to duplicate the MRW closed economy convergence results, thus establishing benchmark credibility. Second, our framework provides econometric specifications to overcome the technical deficiency of the open economy model with perfect capital mobility, that there is no gradual convergence. Our transitory dynamics accommodate empirical reality. Third, we are the first to derive a theoretical justification for Baumol's "three growth clubs" hypothesis, by attributing it to different international borrowing capacities. And finally, we are the first to investigate Barro's significant regional dummies in a structural growth model by attributing them to the "optimal regime switching" of a borrowing economy.

Like MRW, we find that the predictions of the augmented Solow model are consistent with the evidence. These include positive effects of saving rates and negative effects of population growth on the transitional growth paths of per capita GDP, both for the comprehensive sample and for the developing country sample. And like MRW and others, we also find (conditional) convergence at approximately the rate predicted by the augmented Solow model. Our estimated share of capital at about one third is close to the value estimated by Maddison (1987) for the share of non-human capital in GDP.

In order to account for regularities that are missing from the closed economy specification, we then add open economy variables, debt and openness, to the estimation equation. As expected, we find positive effects of the openness variable on growth and negative effects of debt variable. Furthermore, our theoretical models suggest and diagnostic tests confirm, that it is no longer appropriate to treat investment as exogenous in an open economy framework with imperfect capital mobility. We therefore respecify the model as a simultaneous equation system and obtain some new results. We find significant a negative effect of debt on the investment share, and a much larger coefficient of investment on growth. We interpret this as evidence supporting the hypothesis that, much of the negative impact of the African and Latin American dummies can be attributed to these countries' excessive borrowing during the 1970s and subsequent debt service crisis that lowered their growth rates by severely hurting investment. Our results also reconfirm the two-link chain identified by Levine and Renelt (1991), that openness is positively correlated with the investment share and therefore is growth promoting. We interpret this as the economic explanation behind the significant and positive East Asian dummy.

Finally, determining whether and when a specific country is credit constrained is a very complex and difficult issue that involves many factors, and can be decided in practice only empirically. We introduce into a larger growth context a Logit model, that is commonly used in the debt literature, to identify whether a country is being credit constrained. Out of a group of macroeconomic variables and balance sheet data, we find that debt-service ratio, reserves-to-import ratio, average interest on the loans, lagged growth of real GDP per capita, lagged investment share, and share of government spending are important indicators of debt servicing capacity. The Logit model with these as explanatory variables is able to predict the possibility of a country's being credit-constrained with about eighty percent accuracy.

This thesis makes the following contributions to the literature. (1) It provides a synthesized framework that incorporates theoretical results from the cross-country growth literature, the debt literature and the export-led growth literature. (2) It tests empirically the results of open economy growth models with imperfect capital mobility for a cross section of countries for the first time. (3) It provides both theoretical and empirical justification for the previously observed but informally treated "growth club hypothesis" and "African and Latin American dummies" in a more fundamental, mainstream context of closed vs. open economies.

This thesis also helps to indicate the direction of further research. One potential area of fruitful research is econometric use of available panel data. At this stage, it was feasible, in Chapter 6, to use Zellner's seemingly unrelated regression estimation (SURE). This procedure allows for country *random effects* to be correlated over time so as to accommodate aggregate shocks and to improve estimation efficiency. But this still involves rather restrictive assumptions about the error structure of the panel data. An alternative that would allow full variation over time and across countries would be a more general error component model, that breaks the error term into a time-specific error η_t, a country-specific error μ_i, and a pure random error $\varepsilon_{i,t}$ that is associated with each specific observation. Limitations on time series data for debt and human capital variables preclude pursuing this avenue in this thesis.[2]

This thesis has introduced external variables both theoretically and empirically into the mainstream literature on economic growth. It is hoped that it will inspire further research.

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[2] The only such paper known to the author is Knight, Loayza and Villanueva (1992), which deals with only five cross-sections over the 25 years, due to limited time series data on human capital and trade policy.

Appendix A. Log-linear Approximation of Transitory Paths Around the Steady State

According to the Taylor theorem, any function of a variable z, *w(z)*, can be expressed as a sum of a series, and the first order approximation of such a sum is

(A.1) $$w(z) = w(z_0) + (z - z_0)\left.\frac{dw}{dz}\right|_{z_0}$$

Now let the relevant variable and function be

$$z = \ln y_t \quad and \quad w(z) = \frac{dz}{dt} = \frac{d \ln y_t}{dt},$$

and let the linear approximation be centered around the steady state value of the natural logarithm of adjusted output, $z_0 = \ln y^*$. We apply Taylor series approximation equation (A.1) to the variable and the function defined above,

(A.2) $$\frac{d \ln y_t}{dt} = \frac{d \ln y^*}{dt} + \left(\ln y_t - \ln y^*\right)\left.\left[\frac{d\left(d \ln y_t / dt\right)}{d \ln y_t}\right]\right|_{\ln y^*}$$

At steady state, the growth rate of y_t is zero, so the first term disappears. The second term requires us to evaluate the derivative of $\frac{d \ln y_t}{dt}$ with respect to ($\ln y_t$) at steady state value $\ln y^*$. First notice the intensive form of production function implies that

$$\ln y_t = \alpha \ln k_t + \beta \ln h_t .$$

We can expand the function $\frac{d \ln y_t}{dt}$ by substitution using this relationship.

$$\frac{d\ln y_t}{dt} = \frac{d(\alpha \ln k_t + \beta \ln h_t)}{dt}$$

$$= \frac{\alpha}{k_t}\frac{dk_t}{dt} + \frac{\beta}{h_t}\frac{dh_t}{dt}$$

$$= \frac{\alpha}{k_t}\left[s_k y_t - (n+g+\delta)k_t\right] + \frac{\beta}{h_t}\left[s_h y_t - (n+g+\delta)h_t\right]$$

$$= \alpha s_k \frac{y_t}{k_t} + \beta s_h \frac{y_t}{h_t} - (\alpha + \beta)(n+g+\delta)$$

Now take the derivative with respect to $\ln y_t$,

$$\frac{d(d\ln y_t / dt)}{d\ln y_t} = \alpha s_k \frac{d(y_t/k_t)}{d(\ln y_t)} + \beta s_h \frac{d(y_t/h_t)}{d(\ln y_t)}$$

$$= \alpha s_k \frac{k_t \frac{dy_t}{d\ln y_t} - y_t \frac{dk_t}{d\ln y_t}}{k_t^2} + \beta s_h \frac{h_t \frac{dy_t}{d\ln y_t} - y_t \frac{dh_t}{d\ln y_t}}{h_t^2}$$

$$= \alpha s_k \frac{k_t y_t - y_t^2 \frac{dk_t}{dy_t}}{k_t^2} + \beta s_h \frac{h_t y_t - y_t^2 \frac{dh_t}{dy_t}}{h_t^2}$$

$$= (\alpha s_k \frac{y_t}{k_t} + \beta s_h \frac{y_t}{h_t}) - \left[\alpha s_k \frac{y_t^2}{k_t^2}\frac{dk_t}{dy_t} + \beta s_h \frac{y_t^2}{h_t^2}\frac{dh_t}{dy_t}\right]$$

$$= (\alpha s_k \frac{y_t}{k_t} + \beta s_h \frac{y_t}{h_t}) - \left[\frac{d\ln y_t - \beta d\ln h_t}{d\ln k_t} s_k (\frac{y_t}{k_t})(\frac{y_t}{k_t}\frac{dk_t}{dy_t}) + \beta s_h (\frac{y_t}{h_t})(\frac{y_t}{h_t}\frac{dh_t}{dy_t})\right]$$

$$= (\alpha s_k \frac{y_t}{k_t} + \beta s_h \frac{y_t}{h_t}) - s_k \frac{y_t}{k_t}\frac{d\ln y_t}{d\ln k_t}\frac{d\ln k_t}{d\ln y_t} + \beta\left[s_k \frac{y_t}{k_t} - s_h \frac{y_t}{h_t}\right]\frac{d\ln h_t}{d\ln y_t}$$

$$= (\alpha s_k \frac{y_t}{k_t} + \beta s_h \frac{y_t}{h_t} - s_k \frac{y_t}{k_t}) + \beta\left[s_k \frac{y_t}{k_t} - s_h \frac{y_t}{h_t}\right]\frac{d\ln h_t}{d\ln y_t}$$

The next step is to evaluate the above expression in the steady state. Notice each term is a function of output to capital ratio y_t/k_t or output to human capital ratio y_t/h_t and bear in mind that in the steady state these ratios are uniquely determined by the following

$$\frac{y^*}{k^*} = (n+g+\delta)/s_k$$

$$\frac{y^*}{h^*} = (n+g+\delta)/s_h$$

Using these steady state relationships to evaluate the above expression for the derivative will result a drop out of the second term in the brackets. Therefore,

$$\left[\frac{d(d\ln y_t/dt)}{d\ln y_t}\right]\Bigg|_{\ln y^*} = (\alpha - 1)s_k\frac{y^*}{k^*} + \beta s_h\frac{y^*}{h^*}$$
$$= -(1-\alpha-\beta)(n+g+\delta)$$

Consequently, the convergence equation (A.1) becomes,

$$\frac{d\ln y_t}{dt} = \lambda(\ln y^* - \ln y_t)$$

where

$$\lambda = (1-\alpha-\beta)(n+g+\delta).$$

Appendix B. Solving the Time Path for Debt b

Starting from equation (5.10):

$$\text{(5.10)} \qquad \dot{b} = (\theta - n)b + \left[\bar{c} - \left(f(k) - i - \frac{a}{2}i^2\right)\right]$$

The differential equation (10) is in the following general form. (Chiang 1984, Section 18.3-4, pp 480-489).

$$\text{(B.1)} \qquad \frac{dy(t)}{dt} + \mu(t)y(t) = \varpi(t)$$

Its solution is given by

$$\text{(B.2)} \qquad y(t) = e^{-\int \mu(t)dt}\left[A + \int \varpi(t)\, e^{\int \mu(t)dt}\, dt\right]$$

where A is to be definitized by initial conditions.

Here $\int \mu(t)dt = \int -(\theta - n)dt = -(\theta - n)t + k$ (k is arbitrary)

$$\int \varpi(t)\, e^{\int \mu(t)dt}\, dt = \int e^{-(\theta - n)t}\left[\bar{c} - \left(f(t) - i - \frac{a}{2}i^2\right)\right]dt$$

so

$$b(t) = e^{(\theta - n)t}\left\{\int\left[\bar{c} - \left(f(k) - i - \frac{a}{2}i^2\right)e^{-(\theta - n)t}dt\right]\right\}$$

$$= e^{(\theta - n)t}\left\{\frac{1}{\theta - n}\int \bar{c}e^{-(\theta - n)t}d[(\theta - n)t] - \int\left(f(k) - i - \frac{a}{2}i^2\right)e^{-(\theta - n)t}dt\right\}$$

$$= \frac{e^{(\theta - n)t}}{\theta - n}(-\bar{c})e^{-(\theta - n)t} - e^{-(\theta - n)t}\left[\int\left(f(k) - i - \frac{a}{2}i^2\right)e^{-(\theta - n)t}dt\right]$$

$$= \frac{\bar{c}}{\theta - n} - e^{-(\theta - n)t}\left[\int\left(f(k) - i - \frac{a}{2}i^2\right)e^{-(\theta - n)t}dt\right]$$

Appendix C. Proof of the Stability of the Linearized (k, i) System

(5.21a) $$\dot{k} = f(k,i) = -(n+\delta)k + i$$

(5.21b) $$\dot{i} = g(k,i) = -\frac{\beta}{a}k^{\beta-1} + (\delta+\theta)i + \frac{(\delta+\theta)}{a}$$

Therefore the reduced linearization around the steady state (k*, i*) where $\dot{k} = \dot{i} = 0$ is given by the following matrix form:

(C.1) $$\begin{bmatrix} \dot{k} \\ \dot{i} \end{bmatrix} = \begin{bmatrix} f_k & f_i \\ g_k & g_i \end{bmatrix}_{(k^*,i^*)} \begin{bmatrix} k \\ i \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \end{bmatrix}$$

Where

$$f_k = -(n+\delta); \qquad f_i = 1$$

$$g_k = -\frac{\beta(\beta-1)}{a}k^{\beta-2}; \qquad g_i = (\delta+\theta)$$

Jacobian evaluated at steady-state (k*, i*) is negative, as shown below.

$$|J_E| = \begin{vmatrix} f_k & f_i \\ g_k & g_i \end{vmatrix}_{(k^*,i^*)} = \begin{vmatrix} -(n+\delta) & 1 \\ -\frac{\beta(\beta-1)}{a}(k^*)^{\beta-2} & (\delta+\theta) \end{vmatrix}$$

(C.2) $$= -(n+\delta)(\delta+\theta) + \frac{\beta(\beta-1)}{a}(k^*)^{\beta-2}$$

$$= -\left[(n+\delta)(\delta+\theta) + \frac{\beta(1-\beta)}{a}(k^*)^{\beta-2}\right] < 0$$

Characteristic Equation of the Reduced Linearized System

$$\begin{vmatrix} r - f_k & -f_i \\ -g_k & r - g_i \end{vmatrix} = r^2 - (tr\, J_E)r + |J_E| = 0$$

$$where \quad tr\, J_E = f_k + g_i = -(n+\delta)+(\delta+\theta) = \theta - n > 0$$

$$|J_E| = -[(n+\delta)(\delta+\theta) + \frac{\beta(1-\beta)}{a}(k^*)^{\beta-2}]$$

$$and \quad r_1,\ r_2 = \frac{tr\, J_E \pm \sqrt{(tr\, J_E)^2 - 4|J_E|}}{2}$$

(C.3)

$$= \frac{(\theta - n) \pm \sqrt{(\theta - n)^2 + 4[(n+\delta)(\delta+\theta) + \frac{\beta(1-\beta)}{a}(k^*)^{\beta-2}]}}{2}$$

Since the absolute value of the square root is such that $\left|\sqrt{(trJ_E)^2 - 4|J_E|}\right| > trJ_E > 0$, both characteristic roots r_1, r_2 are real but distinct, one is positive and the other negative, therefore we have a saddle point steady-state equilibrium which is dynamically stable along the saddle path.

Appendix D. Comparative Statics of the Steady State Equilibrium

(D.1a) $$-(n+\delta)k^* + i^* = 0$$

(D.1b) $$-\frac{\beta}{a}(k^*)^{\beta-1} + (\delta+\theta)i^* + \frac{(\delta+\theta)}{a} = 0$$

(D.1a) and (D.1b) define the equilibrium pairs (k^*, i^*) as functions of the parameters, n, δ, θ, β and a, that is

(D.2a) $$k^* = f(n, \delta, \theta, \beta, a)$$

(D.2b) $$i^* = g(n, \delta, \theta, \beta, a).$$

The partial derivatives of the above functions, evaluated at the steady state are derived as follows:

$$\begin{cases} f_n = -k^* \\ g_n = 0 \end{cases} \quad \begin{cases} f_\delta = -k^* \\ g_\delta = i^* + \frac{1}{a} \end{cases} \quad \begin{cases} f_\theta = 0 \\ g_\theta = i^* + \frac{1}{a} \end{cases}$$

$$\begin{cases} f_\beta = 0 \\ g_\beta = -\frac{1}{a}(k^*)^{\beta-2}[k^* - \beta(1-\beta)] \end{cases} \quad \begin{cases} f_a = 0 \\ g_a = \frac{1}{a^2}[\beta(k^*)^{\beta-1} - (\theta+\delta)] \end{cases}$$

To find out the effect of population growth n, we construct the following system:

$$\begin{bmatrix} f_k & f_i \\ g_k & g_i \end{bmatrix}_{(k^*, i^*)} \begin{bmatrix} \partial k^*/\partial n \\ \partial i^*/\partial n \end{bmatrix} = \begin{bmatrix} -f_n \\ -g_n \end{bmatrix}_{(k^*, i^*)} = \begin{bmatrix} k^* \\ 0 \end{bmatrix},$$

where

$$|J_E| = \begin{vmatrix} f_k & f_i \\ g_k & g_i \end{vmatrix}_{(k^*, i^*)} = \begin{vmatrix} -(n+\delta) & 1 \\ -\frac{\beta(\beta-1)}{a}(k^*)^{\beta-2} & (\delta+\theta) \end{vmatrix} < 0.$$

Therefore

$$\frac{\partial k^*}{\partial n} = \frac{\begin{vmatrix} k^* & 1 \\ 0 & (\delta+\theta) \end{vmatrix}}{|J_E|} = \frac{(\delta+\theta)k^*}{|J_E|} < 0$$

$$\frac{\partial i^*}{\partial n} = \frac{\begin{vmatrix} -(n+\delta) & k^* \\ \frac{\beta(1-\beta)}{a}(k^*)^{\beta-2} & 0 \end{vmatrix}}{|J_E|} = \frac{-\frac{\beta(1-\beta)}{a}(k^*)^{\beta-1}}{|J_E|} > 0$$

In the steady state, the capital stock is lower, the rate of investment is higher, the higher the rate of population growth.

Similarly, we can study the effects of depreciation rate using the following system of equations:

$$\begin{bmatrix} f_k & f_i \\ g_k & g_i \end{bmatrix}_{(k^*,i^*)} \begin{bmatrix} \partial k^*/\partial\delta \\ \partial i^*/\partial\delta \end{bmatrix} = \begin{bmatrix} -f_\delta \\ -g_\delta \end{bmatrix}_{(k^*,i^*)} = \begin{bmatrix} k^* \\ -(i^*+\frac{1}{a}) \end{bmatrix}$$

$$\frac{\partial k^*}{\partial \delta} = \frac{\begin{vmatrix} k^* & 1 \\ -(i^*+\frac{1}{a}) & (\delta+\theta) \end{vmatrix}}{|J_E|} = \frac{(\delta+\theta)k^* + (i^*+\frac{1}{a})}{|J_E|} < 0$$

$$\frac{\partial i^*}{\partial \delta} = \frac{\begin{vmatrix} -(n+\delta) & k^* \\ \frac{\beta(1-\beta)}{a}(k^*)^{\beta-2} & -(i^*+\frac{1}{a}) \end{vmatrix}}{|J_E|} = \frac{(n+\delta)(i^*+\frac{1}{a}) - \frac{\beta(1-\beta)}{a}(k^*)^{\beta-1}}{|J_E|} (?)$$

With the higher depreciation rate, the economy converges to a steady state with a lower level of capital stock. But the effect on steady state investment is ambiguous.

Next, we study the effects of different interest rates on the steady state, which are given in the following system:

$$\begin{bmatrix} f_k & f_i \\ g_k & g_i \end{bmatrix}_{(k^*,i^*)} \begin{bmatrix} \partial k^*/\partial\theta \\ \partial i^*/\partial\theta \end{bmatrix} = \begin{bmatrix} -f_\theta \\ -g_\theta \end{bmatrix}_{(k^*,i^*)} = \begin{bmatrix} 0 \\ -(i^*+\frac{1}{a}) \end{bmatrix}$$

Which can be solved as follows:

$$\frac{\partial k^*}{\partial \theta}=\frac{\begin{vmatrix}0 & 1\\ -(i^*+\frac{1}{a}) & (\delta+\theta)\end{vmatrix}}{|J_E|}=\frac{i^*+\frac{1}{a}}{|J_E|}<0$$

$$\frac{\partial i^*}{\partial \theta}=\frac{\begin{vmatrix}-(n+\delta) & 0\\ \frac{\beta(1-\beta)}{a}(k^*)^{\beta-2} & -(i^*+\frac{1}{a})\end{vmatrix}}{|J_E|}=\frac{(n+\delta)(i^*+\frac{1}{a})}{|J_E|}<0$$

Both steady state capital stock and the investment rate go down as interest rate increases.

Next, we study the effect of the capital share parameter in the production function:

$$\begin{bmatrix}f_k & f_i\\ g_k & g_i\end{bmatrix}_{(k^*,i^*)}\begin{bmatrix}\partial k^*/\partial\beta\\ \partial i^*/\partial\beta\end{bmatrix}=\begin{bmatrix}-f_\beta\\ -g_\beta\end{bmatrix}_{(k^*,i^*)}=\begin{bmatrix}0\\ \frac{1}{a}(k^*)^{\beta-2}[k^*+\beta(1-\beta)]\end{bmatrix}$$

Which can be solved as follows:

$$\frac{\partial k^*}{\partial \beta}=\frac{\begin{vmatrix}0 & 1\\ \frac{1}{a}(k^*)^{\beta-2}[k^*+\beta(1-\beta)] & (\delta+\theta)\end{vmatrix}}{|J_E|}=\frac{-\frac{1}{a}(k^*)^{\beta-2}[k^*+\beta(1-\beta)]}{|J_E|}>0$$

$$\frac{\partial i^*}{\partial \beta}=\frac{\begin{vmatrix}-(n+\delta) & 0\\ \frac{\beta(1-\beta)}{a}(k^*)^{\beta-2} & \frac{1}{a}(k^*)^{\beta-2}[k^*+\beta(1-\beta)]\end{vmatrix}}{|J_E|}=\frac{-\frac{1}{a}(n+\delta)(k^*)^{\beta-2}[k^*+\beta(1-\beta)]}{|J_E|}>0$$

Last but not the least, the effects of adjustment cost parameter a can be studied in the following system:

$$\begin{bmatrix}f_k & f_i\\ g_k & g_i\end{bmatrix}_{(k^*,i^*)}\begin{bmatrix}\partial k^*/\partial\alpha\\ \partial i^*/\partial\alpha\end{bmatrix}=\begin{bmatrix}-f_\alpha\\ -g_\alpha\end{bmatrix}_{(k^*,i^*)}=\begin{bmatrix}0\\ \frac{1}{a^2}[-\beta(k^*)^{\beta-1}+(\delta+\theta)]\end{bmatrix}.$$

which can be solved as follows:

$$\frac{\partial k^*}{\partial a} = \frac{\begin{vmatrix} 0 & 1 \\ \frac{1}{a^2}[-\beta(k^*)^{\beta-1} + (\delta+\theta)] & (\delta+\theta) \end{vmatrix}}{|J_E|} = \frac{\beta(k^*)^{\beta-1} - (\delta+\theta)}{a^2|J_E|} \qquad (?)$$

$$\frac{\partial i^*}{\partial a} = \frac{\begin{vmatrix} -(n+\delta) & 0 \\ \frac{\beta(1-\beta)}{a}(k^*)^{\beta-2} & \frac{1}{a^2}[-\beta(k^*)^{\beta-1} + (\delta+\theta)] \end{vmatrix}}{|J_E|} = \frac{(n+\delta)[\beta(k^*)^{\beta-1} - (\delta+\theta)]}{a^2|J_E|} \qquad (?)$$

The direction of effects of different adjustment costs are ambiguous for both the capital stock and the investment variables.

Appendix E. Data Sources, Definitions of Variables, and Sample of Countries

Data Source:

For cross country growth and investment equations, the basic data used in this thesis are annual observations for the period 1960 to 1985, for 98 countries. The following variables were taken from Summers and Huston (1991), Penn World Tables (Mark 5):

y_t	real GDP per capital in year t
s_k	real investment to GDP ratio (average over the period)
n	growth of population (average over the period)
T	exports and imports to GDP ratio (average over the period).

The following variable was taken from Mankiw, Romer and Weil (1992):

s_h	percent of working age population enrolled in secondary school (average over the period).

The following dummies variables were constructed as in Barro (1991) and Barro and Lee (1993):

D1	:	dummy variable for sub-Saharan Africa (32 countries)
D2	:	dummy variable for Latin American (21 countries in South and Central American and Mexico)
D3	:	dummy variable for East Asia (7 countries).

The following variable was taken from the World Debt Tables (1993-1994 STAR* edition) for 76 developing countries, and for the same variable for 22 OECD countries was compiled by the author from the International Statistics Yearbook and Government Statistics Yearbook, various years:

d/y	:	debt to GDP ratio (average over the period).

For estimating debt rescheduling using a Logit model, data are annual observations for the period 1970-1990 for 71 developing countries. Additional variables were taken from the World Debt Tables as follows:

RES	:	a dichotomous (1, 0) dummy variable indicating rescheduling (1) or otherwise (0).
ds/x	:	debt service ratio, defined as total debt service to exports ratio
rs/m	:	reserves to import ratio measured in months
ds/ki	:	debt service to capital inflow ratio, where capital inflow includes FDI, grant, and portfolio equity investment)
r	:	average interest rate
gy	:	growth rate of real GDP
g	:	share of government to GDP.

Composition of Samples

The countries in various samples are listed in the following table. (Workbook MRW.xls)

Variables
- **y60 (y85):** real GDP per capita in 1960 (1985).
- **n:** average rate of population growth during 1960-1985.
- **gy:** growth rate of per capita GDP, averaged over 1960-1985.
- **Sk:** saving rate as proxied by average investment share of GDP over 1960-1985.
- **Sh:** investment rate in human capital as proxied by school enrollment ratio.
- **OPEN:** exports and imports share of GDP, averaged over 1960-1985.
- **D1 (D2) [D3]:** dummy variable for sub-Saharan Africa (Latin America) [East Asia].
- **d/y:** average debt-to-GDP ratios over 1960-1985.
- **D4:** control variable for switching from the comprehensive sample to the developing country sample.

50	98	Variable # or Source	PWT55		1	2	4	5	25	MRW	D Af	D L.A	E.A	WDT	D.OECD.
		Country\Variable	y60	y85	n	gy	Sk	g	OPEN	Sh	D1	D2	D3	d/y	D4
1	1	"ALGERIA "	1717	2951	2.82	2.17	23.5	13.63	55.4	4.5	0	0	0	37.9	0
2	2	"ANGOLA "	879	662	2.32	-1.13	3.84	22.53	57.2	1.8	1	0	0	46.6	0
3	3	"BENIN "	1122	1067	2.72	-0.2	4.26	24.7	48.5	1.8	1	0	0	32.9	0
4	4	"BOTSWANA "	552	2252	3.2	5.62	23.4	16.96	94.5	2.9	1	0	0	35.9	0
5	5	"BURKINA FASO "	473	516	2.39	0.35	9.1	12.74	29.4	0.4	1	0	0	19.4	0
6	6	"BURUNDI "	593	510	1.89	-0.6	5.07	14.29	26.9	0.4	1	0	0	15.1	0
7	7	"CAMEROON "	701	1432	2.58	2.86	8.02	16.37	47.7	3.4	1	0	0	28.6	0
9	8	"CENTRAL AFR.R."	661	596	2	-0.41	8.24	29.34	64.4	1.4	1	0	0	27.6	0
10	9	"CHAD "	667	383	1.97	-2.22	3.61	29.03	47.7	0.4	1	0	0	24.2	0
12	10	"CONGO "	1059	2540	2.85	3.5	13.2	33.05	102	3.8	1	0	0	78.9	0
14	11	"EGYPT "	770	1859	2.35	3.53	5.27	29.94	48.9	7	0	0	0	81.2	0
15	12	"ETHIOPIA "	247	283	2.62	0.54	5.67	18.9	26.2	1.1	1	0	0	20.1	0
18	13	"GHANA "	863	759	2.46	-0.51	7.89	15.49	31.6	4.7	1	0	0	33.5	0
21	14	"IVORY COAST "	975	1499	3.76	1.72	11.8	15.54	69.3	2.3	1	0	0	74.1	0
22	15	"KENYA "	642	772	3.69	0.74	18	19.9	59.8	2.4	1	0	0	45.9	0
24	16	"LIBERIA "	691	805	2.96	0.61	14.3	19.62	96.4	2.5	1	0	0	58.7	0
25	17	"MADAGASCAR "	1161	745	2.51	-1.77	1.41	13.79	36.4	2.6	1	0	0	31.6	0
26	18	"MALAWI "	371	499	2.84	1.19	11.9	18.71	60.2	0.6	1	0	0	60.3	0
27	19	"MALI "	499	515	2.28	0.13	6.45	18.84	37.2	1	1	0	0	66.4	0
28	20	"MAURITANIA "	862	809	2.29	-0.25	11.2	28.95	92.4	1	1	0	0	108	0
29	21	"MAURITIUS "	2803	4136	1.74	1.56	11.6	13.7	89.5	7.3	1	0	0	30	0
30	22	"MOROCCO "	790	1889	2.47	3.49	10.9	15.06	45.5	3.6	0	0	0	56.3	0
31	23	"MOZAMBIQUE "	1129	697	2.41	-1.93	1.99	21.12	50.8	0.7	1	0	0	82.9	0
33	24	"NIGER "	503	533	2.83	0.23	8.44	18.43	37.9	0.5	1	0	0	31.7	0
34	25	"NIGERIA "	560	860	2.63	1.72	14.5	18.5	29.9	2.3	1	0	0	11.8	0
36	26	"RWANDA "	519	731	3.18	1.37	3.75	19.15	30	0.4	1	0	0	10.9	0
37	27	"SENEGAL "	1016	1109	2.41	0.35	6.07	21.72	67.2	1.7	1	0	0	47.7	0
40	28	"SOMALIA "	1015	739	3	-1.27	9.77	14.29	51.7	1.1	1	0	0	97.5	0
41	29	"SOUTH AFRICA "	2109	3354	2.24	1.86	21.6	15.88	54.2	3	0	0	0	2.38	0
44	30	"TANZANIA "	315	452	2.99	1.44	15.6	27.35	44.7	0.5	1	0	0	41.4	0
45	31	"TOGO "	364	609	2.79	2.06	19.3	21.01	89	2.9	1	0	0	71.6	0
46	32	"TUNISIA "	1088	2704	2.17	3.64	17.1	16.48	61.9	4.3	1	0	0	42.6	0
47	33	"UGANDA "	680	465	3.07	-1.52	9.67	20.81	171	1.1	1	0	0	54.4	0
48	34	"ZAIRE "	459	422	2.74	-0.34	4.8	19.54	29.5	3.6	1	0	0	35	0
49	35	"ZAMBIA "	944	774	3.06	-0.79	27.2	30.79	85.1	2.4	1	0	0	79.6	0
50	36	"ZIMBABWE "	990	1178	3.39	0.7	20.4	12.09	63.9	4.4	1	0	0	18.8	0
54	37	"CANADA "	7288	15695	1.36	3.07	25.5	11.87	45.2	10.6	0	0	0	14.80	1
55	38	"COSTA RICA "	2021	3258	2.74	1.91	17.2	18.75	63.9	7	0	1	0	74.8	0
57	39	"DOMINICAN REP."	1162	2076	2.63	2.32	15.7	11.59	45.1	5.8	0	1	0	33.3	0
58	40	"EL SALVADOR "	1372	1727	2.46	0.92	9.27	17.26	58.3	3.9	0	1	0	30.6	0
60	41	"GUATEMALA "	1641	2056	2.87	0.9	10.4	8.01	37.3	2.4	0	1	0	14.3	0
61	42	"HAITI "	873	860	1.69	-0.06	5.9	15.46	37.6	1.9	0	1	0	20.6	0
62	43	"HONDURAS "	1007	1303	3.27	1.03	14.3	14.53	61.6	3.7	0	1	0	48.7	0
63	44	"JAMAICA "	1788	2128	1.42	0.7	25.2	9.98	82.3	11.2	0	1	0	89	0
64	45	"MEXICO "	2809	5289	2.88	2.53	18.2	6.9	19.1	6.6	0	1	0	34.5	0
65	46	"NICARAGUA "	1466	1611	2.92	0.38	12.6	12.05	58.5	5.8	0	1	0	91.7	0
66	47	"PANAMA "	1520	3371	2.58	3.19	24.1	22.35	81.4	11.6	0	1	0	72	0

bles	y60 (y85): real GDP per capita in 1960 (1985).
	n: average rate of population growth during 1960-1985.
	gy: growth rate of per capita GDP, averaged over 1960-1985.
	Sk: saving rate as proxied by average investment share of GDP over 1960-1985.
	Sh: investment rate in human capital as proxied by school enrollment ratio.
	OPEN: exports and imports share of GDP, averaged over 1960-1985.
	D1 (D2) [D3]: dummy variable for sub-Saharan Africa (Latin America) [East Asia].
	d/y: average debt-to-GDP ratios over 1960-1985.
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2	"ANGOLA "	879	662	2.32	-1.13	3.84	22.53	57.2	1.8	1	0	0	46.6	0
3	"BENIN "	1122	1067	2.72	-0.2	4.26	24.7	48.5	1.8	1	0	0	32.9	0
4	"BOTSWANA "	552	2252	3.2	5.62	23.4	16.96	94.5	2.9	1	0	0	35.9	0
5	"BURKINA FASO "	473	516	2.39	0.35	9.1	12.74	29.4	0.4	1	0	0	19.4	0
6	"BURUNDI "	593	510	1.89	-0.6	5.07	14.29	26.9	0.4	1	0	0	15.1	0
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8	"CENTRAL AFR.R."	661	596	2	-0.41	8.24	29.34	64.4	1.4	1	0	0	27.6	0
9	"CHAD "	667	383	1.97	-2.22	3.61	29.03	47.7	0.4	1	0	0	24.2	0
10	"CONGO "	1059	2540	2.85	3.5	13.2	33.05	102	3.8	1	0	0	78.9	0
11	"EGYPT "	770	1859	2.35	3.53	5.27	29.94	48.9	7	0	0	0	81.2	0
12	"ETHIOPIA "	247	283	2.62	0.54	5.67	18.9	26.2	1.1	1	0	0	20.1	0
13	"GHANA "	863	759	2.46	-0.51	7.89	15.49	31.6	4.7	1	0	0	33.5	0
14	"IVORY COAST "	975	1499	3.76	1.72	11.8	15.54	69.3	2.3	1	0	0	74.1	0
15	"KENYA "	642	772	3.69	0.74	18	19.9	59.8	2.4	1	0	0	45.9	0
16	"LIBERIA "	691	805	2.96	0.61	14.3	19.62	96.4	2.5	1	0	0	58.7	0
17	"MADAGASCAR "	1161	745	2.51	-1.77	1.41	13.79	36.4	2.6	1	0	0	31.6	0
18	"MALAWI "	371	499	2.84	1.19	11.9	18.71	60.2	0.6	1	0	0	60.3	0
19	"MALI "	499	515	2.28	0.13	6.45	18.84	37.2	1	1	0	0	66.4	0
20	"MAURITANIA "	862	809	2.29	-0.25	11.2	28.95	92.4	1	1	0	0	108	0
21	"MAURITIUS "	2803	4136	1.74	1.56	11.6	13.7	89.5	7.3	1	0	0	30	0
22	"MOROCCO "	790	1889	2.47	3.49	10.9	15.06	45.5	3.6	0	0	0	56.3	0
23	"MOZAMBIQUE "	1129	697	2.41	-1.93	1.99	21.12	50.8	0.7	1	0	0	82.9	0
24	"NIGER "	503	533	2.83	0.23	8.44	18.43	37.9	0.5	1	0	0	31.7	0
25	"NIGERIA "	560	860	2.63	1.72	14.5	18.5	29.9	2.3	1	0	0	11.8	0
26	"RWANDA "	519	731	3.18	1.37	3.75	19.15	30	0.4	1	0	0	10.9	0
27	"SENEGAL "	1016	1109	2.41	0.35	6.07	21.72	67.2	1.7	1	0	0	47.7	0
28	"SOMALIA "	1015	739	3	-1.27	9.77	14.29	51.7	1.1	1	0	0	97.5	0
29	"SOUTH AFRICA "	2109	3354	2.24	1.86	21.6	15.88	54.2	3	0	0	0	2.38	0
30	"TANZANIA "	315	452	2.99	1.44	15.6	27.35	44.7	0.5	1	0	0	41.4	0
31	"TOGO "	364	609	2.79	2.06	19.3	21.01	89	2.9	1	0	0	71.6	0
32	"TUNISIA "	1088	2704	2.17	3.64	17.1	16.48	61.9	4.3	1	0	0	42.6	0
33	"UGANDA "	680	465	3.07	-1.52	9.67	20.81	171	1.1	1	0	0	54.4	0
34	"ZAIRE "	459	422	2.74	-0.34	4.8	19.54	29.5	3.6	1	0	0	35	0
35	"ZAMBIA "	944	774	3.06	-0.79	27.2	30.79	85.1	2.4	1	0	0	79.6	0
36	"ZIMBABWE "	990	1178	3.39	0.7	20.4	12.09	63.9	4.4	1	0	0	18.8	0
37	"CANADA "	7288	15695	1.36	3.07	25.5	11.87	45.2	10.6	0	0	0	14.80	1
38	"COSTA RICA "	2021	3258	2.74	1.91	17.2	18.75	63.9	7	0	1	0	74.8	0
39	"DOMINICAN REP."	1162	2076	2.63	2.32	15.7	11.59	45.1	5.8	0	1	0	33.3	0
40	"EL SALVADOR "	1372	1727	2.46	0.92	9.27	17.26	58.3	3.9	0	1	0	30.6	0
41	"GUATEMALA "	1641	2056	2.87	0.9	10.4	8.01	37.3	2.4	0	1	0	14.3	0
42	"HAITI "	873	860	1.69	-0.06	5.9	15.46	37.6	1.9	0	1	0	20.6	0
43	"HONDURAS "	1007	1303	3.27	1.03	14.3	14.53	61.6	3.7	0	1	0	48.7	0
44	"JAMAICA "	1788	2128	1.42	0.7	25.2	9.98	82.3	11.2	0	1	0	89	0
45	"MEXICO "	2809	5289	2.88	2.53	18.2	6.9	19.1	6.6	0	1	0	34.5	0
46	"NICARAGUA "	1466	1611	2.92	0.38	12.6	12.05	58.5	5.8	0	1	0	91.7	0
47	"PANAMA "	1520	3371	2.58	3.19	24.1	22.35	81.4	11.6	0	1	0	72	0

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