An application of Solow's growth model: Case of sub-Saharan Africa

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APPROVAL

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ABSTRACT

This study is prompted by the growing concern over the poor economic performance of Sub-Saharan Africa (SSA) relative to the rest of the world over the past decade. The purpose of the study is to examine how a simple and predictable model like Solow's model can explain per capita income in SSA. Our study consists of cross-sectional-cum-time-series regressions using 32 SSA countries. The time span considered is a 26-year period from 1960 to 1985. The model is based on the empirical framework developed by Mankiw et al. (1992). Our results show that saving has a significantly positive impact on per capita GDP in SSA, while population growth rate, though consistently negative, is significant only at higher levels of data disaggregation. Our findings are consistent with Mankiw et al.’s (1992) which confirm Solow’s predictions that saving has a positive effect on per capita income whereas population growth has a negative effect.
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CHAPTER 1
INTRODUCTION

There is growing concern over the worldwide decline in the rate of economic growth. Aside from the Pacific Rim area, most regions of the world have experienced lower per capita GDP growth rates in the 1970s and 1980s relative to the 1960s.\(^1\) The effects of the economic slowdown on living standards has generated renewed interest in economic growth. It is widely believed that an understanding of the factors influencing economic growth is necessary to formulate appropriate policies to reverse the observed trend.

Although the oil price shock of the 1970s is cited as a turning point in this economic slowdown, this event alone cannot explain the low growth rates that persisted well into the 1980s. In particular, since the oil shock had worldwide repercussions, how do we explain that non-oil exporting countries in the Pacific enjoyed unabated growth for nearly three decades? Similarly, how do we explain that countries with similar initial conditions have experienced divergent economic growth performances in a span of three decades? For example, in the 1960s South

Korea and the Philippines had similar per capita incomes of about $640.² They also had fairly similar demographic and economic features. However, per capita income of South Korea is now three times that of the Philippines. From the 1960s to the 1980s, per capita income in the two countries grew on average at 6.2% and 1.8%, respectively.

Likewise, when Ghana and Malaysia became independent from Great Britain in 1957, they both had "a rich mix of resources," and reserves of foreign currencies.³ Above all, they both had a per capita income of $750. Three and a half decades later, per capita income in Malaysia was $2500, nearly six times that of Ghana.

This relatively slow growth in Ghana's per capita income raises concerns about the potential for economic development in Sub-Saharan Africa (SSA), where many countries have experienced per capita GDP growth rates inferior to Ghana's in the 1980s.⁴ The aggregate growth rate for SSA in the 1980s was -2.6% which stands in sharp contrast with the post-independence performance, when on average SSA countries grew at 2.0% and when investment returned an attractive rate of 30.7% annually.

Recent studies have attempted to shed light on the drastically different growth experiences as discussed above. They have characterized the East Asian performance

²Amount in U.S. dollars is in constant 1975 prices. Data for this paragraph are from R. E. Lucas, "Making a Miracle" Econometrica, March 1993.


⁴See World Bank, Sub-Saharan Africa-From Crisis to Sustainable Growth, 1989.
as "productivity miracles" that allowed the typical worker to produce 6 times more now than what he could produce in the 1960s. According to Lucas (1993) the "miracle economies" have tended to engage in large scale exports of highly sophisticated manufactures. Also, these economies were characterized by a higher degree of urbanization, an increasingly well-educated population, a high savings rate, and a pro-business government. Lucas (1993) argues that those features are indeed part of "any explanation of the growth miracles" but are "not themselves explanations." As such, "one needs...a theory" that can provide a framework for analyzing growth.

Three major growth theories have been formulated over the past 40 years: the Harrod-Domar model, the Solow model, and, lately, the Endogenous Growth model. The Harrod-Domar model explains growth of output in a Keynesian framework, assuming employment of fixed proportions of inputs. It emphasizes the dual character of investment as income creating and as capacity expanding. As such, strict equality between the actual and warranted growth rates is necessary to avert continuous instability and spiralling economic decline. In this model, the economy is balanced on a "knife-edge" equilibrium path because saving and investment decisions are made by different economic agents.


6Lucas refers to economies, such as South Korea, that have experienced outstanding economic performance in the last decades as "miracle economies."
Solow's 1956 growth model discards the fixed proportions assumption and shows that an economy does not necessarily balance on a "razor-edge" path of equilibrium growth. In the Solow model, a country moves toward a steady state equilibrium where capital, labor, and output grow at the same rate. This implies that, in steady state, per capita output and capital-labor ratio do not change. In this model, an economy that is not in equilibrium moves toward steady state through changing capital-labor ratios that arise from (i) a constantly growing population and (ii) changes in the capital stock due to changes in domestic saving. Hence, the saving rate influences long-run standard of living but not growth rate of per capita income. However, the model attributes differences in growth rates between two countries with identical production technologies and saving rates to diverging initial per capita incomes. The model predicts that the country with the lower initial per capita income will grow faster than and catch up with the other. Eventually, the two countries converge toward similar steady state levels.

The endogenous growth theory discards the assumptions of diminishing returns to capital accumulation and of exogenous technological progress. It emphasizes the roles of capital accumulation, externalities, and individual choice effects on human

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7 It can be shown diagrammatically that, for a given production function, a higher saving rate results in a higher per capita income, though not necessarily in a higher per capita consumption. If the saving rate initially corresponds to the Golden Rule level of consumption, increasing the saving rate, ceteris paribus, leads to a decline in per capita consumption. In this respect, steady state is dynamically inefficient.

8 Trade causes convergence to happen more quickly. See, for example, Plosser (1992), page 62.
Although insightful and interesting, the endogenous growth theory relies on variables that are difficult to measure empirically.¹⁰

In this study, we follow Mankiw et al.'s (1992) specification of Solow's model to analyze living standards in Sub-Saharan Africa.¹¹ The findings of Mankiw et al. support Solow's predictions that "[t]he higher the rate of saving, the richer the country [and that the] higher the rate of population growth, the poorer the country."¹² There are compelling reasons for analyzing the influences of saving and population growth in SSA.

First, SSA countries have been lagging in economic performance relative to the rest of the world. Yet, the cross-sectional growth studies to date have mostly analyzed groups comprised of developed as well as developing countries.¹³ Therefore, a study based solely on SSA data can point to some of the economic factors that are pertinent to economic growth in that region.

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⁹ The endogenous theory allows a greater scope for policy in the determination of economic growth. See, for example, Kahn (1992).


¹² Knight et al. (1993) also obtained results supporting Solow's predictions regarding the impacts of saving and population growth on per capita income.

¹³ See, for example, works by Otani and Villanueva (1990), Landau (1983), Kormendi and Meguire (1985), Singh (1985), or Ram (1987).
Second, SSA forms a less heterogeneous group of countries than Less Developed Countries (LDCs) as a whole, such that it is meaningful to study SSA apart from other LDCs. Thus, it is more reasonable to assume identical cross-sectional production functions for SSA than for all LDCs.\textsuperscript{14}

Finally, the major variables explaining the Solow model--saving rate and population growth rate--have displayed alarming trends in SSA over the past decades. Saving rate fell in the 1980s relative to its 1970s level, while population growth rate has been rising steadily since the 1960s.\textsuperscript{15} It is therefore appropriate to use Solow's model to analyze the impact of saving and population growth on SSA's economy.\textsuperscript{16}

The rest of the study is organized as follows. Chapter 2 contains the literature review. Chapter 3 discusses the predictions of the simple Solow model. In Chapter 4, we formulate the specification of the model. The data for SSA is analyzed in Chapter 5. Chapter 6 presents the empirical results. Finally, chapter 7 contains the concluding remarks.

\textsuperscript{14}We performed regressions with the data gathered for this study to test for intercept shifts. The results show that most of the country dummy variables were significant.

\textsuperscript{15}See World Bank, Sub-Saharan Africa--From Crisis to Sustainable Growth, 1989.

CHAPTER 2
LITERATURE REVIEW

Although growth studies share the same purpose of understanding the determinants of economic performance, there is no generally accepted model behind the empirical work to date. Many studies rely on the findings of previous studies or on "common sense" to determine factors affecting growth. In this chapter, we briefly survey the growth literature and discuss the problems associated with them.

I. Growth Accounting Approach

A large body of empirical studies have used a growth accounting identity to explain economic growth. Among them, Denison (1962) derives the sources of economic growth in the U.S. from a Cobb-Douglas production function. Given constant returns to scale and neutral technology, growth in output \( Y \) is given as the sum of growth in capital \( K \), in labor \( L \), and in total factor productivity \( A \) as follows:

\[
\frac{\Delta Y}{Y} = \alpha \frac{\Delta K}{K} + (1-\alpha) \frac{\Delta L}{L} + \frac{\Delta A}{A}
\]

\( \Delta Y \) denotes the percentage change in output, \( \Delta K \) the change in capital, \( \Delta L \) the change in labor, and \( \Delta A \) the change in total factor productivity. The parameter \( \alpha \) represents the share of capital in output.

\( \alpha \) and \( 1-\alpha \) represent the shares of capital and labor in output, respectively.

\( \Delta Y \) denotes the percentage change in output, \( \Delta K \) the change in capital, \( \Delta L \) the change in labor, and \( \Delta A \) the change in total factor productivity. The parameter \( \alpha \) represents the share of capital in output.

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Since growth in total factor productivity cannot be directly measured from economic data, the above breakdown is frequently used to measure the rate of technological change as a residual, that is:

\[
\frac{\Delta A}{A} = \frac{\Delta Y}{Y} - \alpha \frac{\Delta K}{K} - (1-\alpha) \frac{\Delta L}{L}
\]  

(2)

Here growth of output is used to calculate the unaccountable factors that affect growth. Hence the weakness of growth accounting is that it does not specify which variables contribute to growth.

Subsequent research have accounted for a larger set of variables in an attempt to reduce the size of the residual in equation (1) above. Kormendi and Meguire (1985) tested the explanatory relationship of a set of macroeconomic hypotheses with economic growth. The following variables were assumed to affect growth: (i) initial per capita income, (ii) standard deviation of average supply shocks, (iii) average population growth rate,\(^{18}\) (iv) risk-return tradeoff, (v) average money supply growth rate, (vi) growth of the share of government spending, (vii) the degree of openness, and (viii) average growth rate of inflation. Risk-return trade-off and investment ratio were found to be important factors explaining economic growth.

\(^{18}\)Both Kormendi and Meguire (1985) and Grier and Tullock (1989) expect a positive impact from population growth rate. This is contrary to the neoclassical prediction. There seems to be a confusion about the direction of the impact of (i) the growth rate of labor force and (ii) population level, as opposed to population growth rate.
Grier and Tullock (1989) replicated Kormendi and Meguire’s (1985) work using a larger sample of countries. Initial per capita income, population growth, share of government consumption in GDP, and the standard deviations of inflation and of GDP growth were significant and of the expected sign. Inflation, though positive, was not significant. Grier and Tullock (1989) found a "strong convergence effect" for OECD countries. In the case of Africa, their results showed that inflation and government have a significant negative impact on income growth rate.

In a cross-country study of economic growth, Landau (1983) found that the share of government consumption and the level of GDP have a negative impact on the growth rate of GDP, while investment in human capital is positively related to the growth rate of GDP. Other variables, such as energy consumption and per capita agricultural land, do not have a significant impact on growth.

Among growth studies that have focused on developing countries, Otani and Villanueva (1990) find that domestic saving, budgetary share of expenditure on human capital, and growth of exports have positive impacts on growth of per capita GNP, whereas real interest rate on external debt and population growth have

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19 They used a sample of 113 countries. Kormendi and Meguire (1985) used a sample of 47 countries.

20 The impact of the share of government consumption in GDP was positive for the low-income portion of the sample.

21 Budgetary share of expenditure on human capital was not strongly significant.

22 Real interest rate on external debt was not significant. The exclusion of this variable did not affect the signs on the other variables, but improved the significance of domestic saving and exports growth.
negative impacts. Otani and Villanueva (1990) also divide their sample according to income as high, middle, and low-income countries. Their results show a better fit for middle-income countries.\(^{23}\)

Singh's (1985) study was prompted by the observation that some countries with "relatively smaller economic aid (as % of GDP) than many other countries, have achieved a much higher rate of economic growth."\(^{24}\) Singh argues that the controversial results obtained regarding aid arises from the failure to account for the state economic policy employed by the aid-receiving countries. He estimates a linear relationship between growth rate and (i) aid as a percentage of GDP, (ii) domestic saving rate, (iii) log of total population, (iv) log of per capita income, (v) state intervention score, and (vi) two dummy variables for African countries and oil-exporters, respectively. Singh finds that domestic saving has a statistically stronger influence on growth than foreign aid. Also, the results suggest structural changes between the 1970s and 1980s.

Ram (1987) analyses the influence of exports on economic growth in developing countries using a conventional production function and the Feder framework.\(^{25}\) The result of time series regressions show that export is positive and

\(^{23}\)Low-income countries showed some wrong signs and insignificant variables; 55% of the variation in growth rate in high-income countries was explained.

\(^{24}\)Countries listed as small aid receivers were: South Korea, Singapore, Thailand, Cote d'Ivoire, Brazil, Ecuador. Large aid receivers included: Sudan, Chad, Liberia, Mauritania, Niger, Zaire, Zambia.

\(^{25}\)The Feder framework involves two sectors. The export sector results in an "externality" effect on production in the nonexport sector.
significant for about 42% of the countries in the full sample, for 50% of the countries in the middle-income sample, and for about 32% of the countries in the low-income countries. The cross-sectional results show that export growth is positive in all samples.\footnote{In regressions using the conventional and the Feder frameworks, export growth was not significant in four and in one of the eleven samples, respectively.}

There are also a few studies that have focused on Africa. Odedokun (1993) and Wheeler (1984) examine macroeconomic factors as they relate specifically to Africa. Odedokun (1993) uses a cross-section of 42 countries to analyze the factors responsible for the poor economic growth performance of Africa in the 1970s and 1980s. Eighteen variables were introduced. The results show that factors such as export growth, investment in human capital, growth of government consumption, life expectancy at birth, and population size promote growth, whereas factors like inflation, initial per capita income, agricultural share in GDP, and financial deepening display negative influences on GDP growth. The results are however neither consistent nor clear throughout the time period studied, and many of the eighteen variables do not exhibit significant impacts on growth.

Wheeler (1984) discusses the extent to which the slowdown in growth in Africa may have been the result of inappropriate policies or unfortunate environmental circumstances. He finds that the environmental variables seem to have had more
impact on growth than the other variables tested. Policy measures involving the overvaluation of the exchange rate have had an adverse effect on growth.27

Studies such as those above have resulted in "over 50 variables [that] have been found to be significantly correlated with growth."28 However, such studies have no theoretical basis. They resemble stepwise regressions in that independent variables are added to the equation, not as required by the theory, but in order to reduce the error term. Those studies are therefore ad hoc and their results are sensitive to the specified functional form. Levine and Renelt (1992) found that most of the variables that lacked a theoretical basis were not robust.

Moreover, a lack of theoretical basis to justify the use of certain variables may lead to spurious results. Wheeler (1984) points to two econometric problems that may affect the validity of the coefficients estimated in economic growth regression: simultaneity and multicollinearity. He argues that foreign aid, for example, may pose a simultaneity problem because aid is not exogenous; instead, aid tends to flow to countries that are doing "badly." He also argues that the impact of export diversification, mineral exports, and stability of export earnings cannot be determined because they are candidates for multicollinearity. The latter argument is in line with

27 Such measures required some form of rationing of the exchange rate and thus limited importation of capital. This argument is compatible with the view by Grossman and Helpman (1990) that free trade flows allow for spillovers in technology across countries.

Plosser's that "determining the marginal impact on growth of any one of [the correlated variables] may prove difficult."^{29}

II. Endogenous Growth Approach

Recent studies operate within the framework provided by the endogenous growth theory. Here, factors such as investment, externalities, and human capital play a greater role.

Barro (1992) describes the channel of the effect of human capital as (i) a positive effect on investment in physical capital, (ii) a negative effect on fertility rate, and (iii) a positive effect on growth rate when investment and fertility are held constant. The effect of human capital on fertility implies that the rate of growth of population is not exogenous as assumed in the neoclassical growth model. In other words, as the human capital improves--for example, through education--people tend to choose smaller-sized families. Since human capital is one of the independent variables of the model, population growth is no longer determined exogenously; instead it is affected by changes within the model.

Darby (1992) associates the declining growth in the U.S. between 1965 and 1979 to a slowdown in labor-productivity. He also draws attention to the impact of increasing regulation and to the tradeoffs involving the environment and social

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values. Nevertheless, he acknowledges the difficulty of measuring the latter influences.

Solow’s exogenous growth model has been extended to include human capital in some studies. Mankiw et al. (1992) found that Secondary school enrollment ratio has a positive impact on per capita income.

More studies have however concentrated on testing Solow’s prediction of convergence, that is, whether poor countries catch up with rich countries.30 For example, Barro’s (1991) study provides conditional support to convergence. He observes that the expected negative relationship between the initial level of per capita GDP and growth occurs only if human capital is constant. Moreover, human capital is more important than initial level of per capita GDP in determining growth rate. His results show that the prediction of convergence holds only if the ratio of human capital to per capita GDP is high in the poor countries.31

III. Neoclassical Growth Approach

Knight et al. (1993) use a panel of cross-sectional and time series data to test for country-specific effects in Mankiw et al.’s (1992) version of Solow’s model. They argue that the presence of country-specific effects explains the faster rate of conditional convergence observed in their model than in Mankiw et al.’s (1992).

30See Mankiw et al. (1992), Barro (1991), and Barro and Sala-i-Martin (1992), among others.

Knight et al. also find that the saving ratio and measures of technology--openness and government fixed investment--have positive effects on per capita GDP, while population growth has a negative effect.

Mankiw et al.'s (1992) tests of the predictions of Solow's model show that saving has a positive impact on per capita GDP while population growth has a negative impact. They also find that convergence occurs more slowly than theoretically predicted.

Our study is based on Mankiw et al.'s (1992) version of Solow's model. In chapter 4 we derive the equations used by Mankiw et al. (1992). Unlike the studies mentioned above, Mankiw et al.'s (1992) version has a theoretical basis, yet is simple to estimate. Moreover, the study by Knight et al. (1993) confirms Mankiw et al.'s results regarding the variables used in this study.
CHAPTER 3
THE THEORETICAL SOLOW MODEL

This chapter examines the simple Solow growth model. First we describe the basic framework of the model, then we graphically present the steady state conditions, finally we discuss the main predictions of the model.

I. The Basic Solow Model

The model explains growth of output in a neoclassical context. Assuming an aggregate production function with no technological progress or capital depreciation, the basic Solow model can be written as:

\[ Y = F(K, L) \quad (K, L > 0) \]  \hspace{1cm} (1)

where \( Y \) is output, \( K \) is capital, and \( L \) is labor. Assuming a linearly homogeneous production function, we can write:

\[ Y = K^a L^{1-a} \]

---


where (2)

\[
\frac{Y}{L} = f\left(\frac{K}{L}, \frac{L}{L}\right) \quad \text{or} \quad y = f(k) \quad \text{where} \quad y = \frac{Y}{L} \quad \text{and} \quad k = \frac{K}{L}.
\]

Neoclassical assumptions require that

(i) \( f_k = \frac{df}{dk} > 0 \) \quad \text{and} \quad f_l = \frac{df}{dl} > 0 \quad (3) \]

(ii) \( f_{kk} = \frac{d^2f}{dk^2} < 0 \) \quad \text{and} \quad f_{ll} = \frac{d^2f}{dl^2} < 0 \]

that is, (i) the marginal products of capital and of labor are positive, and (ii) diminishing returns to each factor occurs. In other words, the addition of more and more of one factor while holding the other factor constant causes output to increase at a decreasing rate. Diminishing returns imply a production function that is concave to the origin.

Furthermore, Solow assumes that a constant fraction \( s \) of output \( Y \) is saved, and that labor grows exogenously at the exponential rate \( n \). Thus,

\[
\dot{k} = \left(\frac{dk}{dt}\right) = sY = s\cdot Lf(k) \quad (4)
\]

and

\[
\frac{i}{L} = \left(\frac{dL}{dt}\right) = n
\]

so that

\[
\dot{L} = nL \quad (5)
\]
Since $k = \frac{K}{L}$, we can write $K = kL$, which differentiated totally gives:

$$\dot{K} = \dot{k}L + k\dot{L} \quad \text{or} \quad \dot{K} = k\dot{L} + knL$$

Equation (6)

Equating equations (4) and (6) and rearranging terms yields

$$\dot{k} = s.f(k) - kn$$

Equation (7)

where $s.f(k)$ represents saving per worker, and $kn$ represents investment per worker.

Equation (7) shows that capital accumulation is positively related to saving rate and negatively to population growth rate. In other words, the term $s.f(k)$ increases when the saving rate $s$ increases. Therefore, the change in capital stock per worker $\dot{k}$ increases. Similarly, the term $kn$ increases when the population growth rate increases, because there are more new workers to be equipped with capital. However, now the change in capital stock per worker $\dot{k}$ decreases.

If saving per worker equals investment per worker, that is, $s.f(k) = kn$, the economy is said to be in a steady state, where the stock of capital per worker does not change over time. The significance of the condition of steady state rests in the determination of the path of capital formation. The latter is described in the next section. The fact that $\dot{k} = 0$ is the result of long run adjustment and equilibrium rather than the causal condition of stable growth.\textsuperscript{34} Solow shows that if the fixed

\textsuperscript{34}Steady state is not an assumption but a long run result based on the assumption of no technological progress.
proportions assumption of the Harrod-Domar model is rejected, an economy can follow a stable path even when it is not in equilibrium.

II. Steady State: A Graphical Representation

In the Solow model, the economy converges toward a steady state equilibrium, where output, capital, and labor grow at the same rate $n$. As such, per capita output and the capital-labor ratio are constant. The steady state equilibrium occurs at point E in figure 1(a), corresponding to the capital-labor ratio $k^*$. The line $nk$ in figure 1(a) is a linear function of $k$. It represents investment per worker required to equip a labor force growing at rate $n$ while maintaining a constant capital-labor ratio. Along $nk$, the capital-labor ratio is constant.

The curve $sf(k)$ in figure 1(a) represents saving per worker at various levels of the capital-labor ratio. The function increases at a decreasing rate because of the neoclassical assumption of diminishing returns.

The curve $\dot{k}$ in figure 1(b) is the phase line. It represents the vertical distance between $sf(k)$ and $nk$. The shape of the phase line shows the path that capital formation must follow to ensure full employment of inputs at a constant capital-labor ratio.

Unlike the Harrod-Domar model, the economy here converges toward a stable equilibrium, irrespective of whether it starts above or below the steady state capital-labor ratio. For example, if the economy is below equilibrium E, say at point A, saving per worker exceeds investment per worker necessary to maintain a constant
capital-labor ratio. The excess saving is represented by point F in figure 1(b), where the change in capital stock is positive. Since saving strictly equals investment in this
Figure 1: Steady State--A Graphical Representation
model, capital accumulation occurs as the economy continues investing in capital stock. Hence the capital-labor ratio increases and the economy moves toward $k^*$, where $k^* > k_t$.

Conversely, if the economy is above equilibrium $E$, say at point $B$, saving per worker ($OS$) falls short of the amount of investment per worker ($OT$) required to maintain a constant capital-labor ratio. The resulting shortage of capital is represented by point $G$ in figure 1(b), where the change in capital stock is negative. Capital depletion occurs because the growth of the labor force exceeds the growth of the capital stock. Hence, the capital-labor ratio falls from $k_2$ toward $k^*$.

Once the economy reaches a capital-labor ratio of $k^*$, the forces causing change are in equilibrium. The economy is in steady state at point $H$ (figure 1(b)), where $\dot{k} = 0$. Therefore, the capital-labor ratio does not change, and ceteris paribus, the economy experiences constant growth rates and constant living standard indefinitely.

III. Predictions of the Solow Model

Two important results based on saving and population growth are derived from Solow’s model. Equation (7) showed that the stock of capital per worker increases over time with the saving rate and decreases with the labor growth rate. We now individually analyze the impact of saving and population growth on economic growth.
(a) Changes in the saving rate

One proposition of the Solow model is that, *ceteris paribus*, the higher the saving rate, the higher the output per capita. This result is depicted in figure 2. With an initial saving rate $s_1$, there is a steady state equilibrium at $E_1$. The initial steady state capital-labor ratio is $k_1$ and the resulting output per capita is at $y_1$.

Let the saving rate increase to $s_2$ (where $s_2 > s_1$). The new steady state equilibrium is at $E_2$. At the new capital-labor ratio $k_2$, per capita output is now $y_2$, which is greater than $y_1$. The higher saving rate makes more capital accumulation possible. Per capita income therefore increases because output is a direct positive function of capital.

(b) Changes in the rate of population growth

The other proposition of the Solow model is that, *ceteris paribus*, the higher the population growth rate, the lower the output per capita. As figure 3 shows, an increase in population growth rate from $n_1$ to $n_2$ results in a new investment line $njk$. The capital-labor ratio decreases from $k_1$ to $k_2$. Output falls from $y_1$ to $y_2$ as the steady state equilibrium moves from $E_1$ to $E_2$.

The model shows that an increase in population in excess of saving available to support a constant capital-labor ratio results in capital depletion. Therefore, the capital-labor ratio falls, as does the marginal product of capital. Hence, total output and output per capita also falls.
Figure 2: Changes in the Saving Rate

Figure 3: Changes in the Population Growth Rate
CHAPTER 4
THE EMPIRICAL MODEL

In the previous chapter we examined the basic predictions of Solow's model. However, for econometric estimation purposes, we need to set up the proper functional form that will allow us to determine the sign and magnitude of the effects of saving and population growth on per capita income. The Cobb-Douglas production function is a convenient functional form used in most empirical growth literature. This chapter follows the specification of Solow's basic model derived by Mankiw, Romer, and Weil (1992). The incorporation of technology, depreciation, and human capital into Solow's model by Mankiw et. al. (1992) is shown in sections II and III.

I. Specification of the Basic Solow Model

The Cobb-Douglas production function takes the form

\[ Y = F(K, L) = K^\alpha L^{1-\alpha} \quad (0 < \alpha < 1) \] (1)

where \( \alpha \) and \( (1 - \alpha) \) represent the share of capital in income and the share of labor in income, respectively. The Cobb-Douglas production function is linearly homogeneous. Therefore we write equation (1) as

\[ y = f(k) = k^\alpha \] (2)
Combining equation (2) above and equation (7) of chapter 3 and simplifying yields

\[ \ln y = \frac{\alpha}{1-\alpha} \ln s - \frac{\alpha}{1-\alpha} \ln n \]  

which partially differentiated gives

\[ \frac{\partial \ln y}{\partial \ln s} = \frac{\alpha}{1-\alpha} > 0 \]

\[ \frac{\partial \ln y}{\partial \ln n} = -\frac{\alpha}{1-\alpha} < 0 \]  

Equation (6) shows that, ceteris paribus, a 1% increase in saving rate will increase per capita output by \( \left( \frac{\alpha}{1-\alpha} \right) \% \), whereas a 1% increase in population growth rate will decrease per capita output by \( \left( \frac{\alpha}{1-\alpha} \right) \% \). If the share of capital in income (\( \alpha \)) is roughly one-third, the model predicts an elasticity of per capita income of

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35See Appendix A.
approximately .5 with respect to saving rate and approximately -.5 with respect to population growth rate.\textsuperscript{36}

II. Accounting for Technology and Depreciation

The predictions of the model discussed in chapter 3 were based on the assumption of no technological progress. We saw that an economy follows a time path of capital formation that relentlessly leads toward steady state. In steady state, output per capita remains indefinitely constant. In order to understand observable increases in standard of living, we will here relax this assumption. The section will use Solow's model to account for the impact of technological growth and depreciation.

Consider the labor-augmenting production function

\[ Y = F(K, AL) = K^a(AL)^{1-a} \]

which is written as

\[ \frac{Y}{AL} = f(k) = k^a \quad (8) \]

We assume that labor and technology grow exogenously at rates \( n \) and \( g \) respectively, that is

\[ L_t = L_0 e^{nt} \quad (9) \]

\[ A_t = A_0 e^{gt} \quad (10) \]

\textsuperscript{36}De Long and Summers (1991) found a GDP growth elasticity of one-third percentage point with respect to machinery and equipment investment for the period 1960-1985.
and the number of effective units of labor grows at rate \((n + g)\). If the capital stock is assumed to depreciate at rate \(\delta\), the time path of capital formation is given by

\[
\frac{dK}{dt} = \dot{K} = sY - \delta K
\]

(11)

From equation (8) we have \(\frac{Y}{AL} = k^a\) or \(\frac{Y}{L} = A k^a\). Thus, combining equations (8) and (11) and simplifying\(^3\) gives

\[
\frac{Y}{L} = A_0 e^{gt}\left[\frac{s}{(\delta + n + g)}\right]^{\frac{\alpha}{1-\alpha}}
\]

(16)

Taking natural logarithms on both sides of equation (16) gives

\[
\ln y = \ln A_0 + gt + \frac{\alpha}{1-\alpha} \ln s - \frac{\alpha}{1-\alpha} \ln (\delta + n + g)
\]

(17)

The result generated by equation (17) is similar to that generated by equation (6).

III. Accounting for Human Capital

Equations (6) and (17) showed that population growth has a negative impact on economic growth. However, studies have emphasized quality of population (rather than its magnitude alone) as contributing positively to economic growth. For

\(^3\)See Appendix B.
example, a study by Azariadis and Drazen38 (1990) found that a "highly literate labor force" was crucial to rapid growth in the postwar period. Also, Lucas (1993) emphasizes the role of a highly educated population in the economic success of East Asian economies. Therefore, from an empirical point of view, failure to account for human capital may result in specification bias. Furthermore, from a theoretical point of view, if returns to all reproducible capital are constant (that is, if $\alpha + \beta = 1$), steady state is not possible in this model.39

In this section, we use the augmented Solow model developed by Mankiw et al. to examine the importance of human capital.40 The augmented model expands on the general production function described earlier by including human capital as:

$$Y = F(K, H, AL)$$

(18)

where $H$ is the stock of human capital. We retain all previous assumptions, but modify the saving rate as follows:

(i) $s_k$ is the fraction of income invested in physical capital;

(ii) $s_h$ is the fraction of income invested in human capital.

---


40Mankiw et al. report that the Solow model accurately predicts the signs of the variables, but not their magnitude. In the endogenous literature this is attributed to the fact that the impact of human capital is more than traditionally accounted for (that is, where $\alpha = 0.3$ and human capital is included in labor). See Mankiw (1992), p. 89, and Mankiw et al. (1992). Therefore, Mankiw et al. introduce human capital into the model to adjust for a possible specification error.
We further assume that the cost of producing a unit of human capital, physical capital, or consumer good is the same. Also, we assume that human capital and physical capital depreciate at the same rate $\delta$.\footnote{We follow similar assumptions made by Mankiw et al. The two depreciation rates are assumed equal for purposes of algebraic simplification.}

The Cobb-Douglas production function in this model can therefore be written as:

\[ Y = K^\alpha H^\beta AL^{(1-\alpha-\beta)} \quad (0 < \beta < 1) \tag{19} \]

where $(\alpha + \beta < 1)$, that is, decreasing returns to all capital occurs. The production function can be expressed per effective unit of labor as

\[ y = f(k, h, 1) \]

\[ y = k^\alpha h^\beta \tag{20} \]

where $y = \frac{Y}{AL}$, $k = \frac{K}{AL}$, and $h = \frac{H}{AL}$.

Changes in physical and human capital stocks can be written as

\[ \frac{dK}{dt} = I_k = s_k Y - \delta K \tag{21a} \]

\[ \frac{dH}{dt} = I_h = s_h Y - \delta H \tag{21b} \]
We use equations (20), (21a), and (21b) to derive the relationship between the stocks of physical and human capital and saving and population growth rates as

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

(24a)

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

(24b)

Equations (24a) and (24b) show that the stock of physical and human capital varies directly with saving rate, and inversely with depreciation and the rate of population growth.

The effect on per capita income can be examined by replacing equations (24a) and (24b) into equation (20). Upon simplification we obtain

\[ \ln y = \ln A_0 + gt + \left( \frac{\alpha}{1 - \alpha - \beta} \right) \ln s_k + \left( \frac{\beta}{1 - \alpha - \beta} \right) \ln s_h - \left( \frac{\alpha + \beta}{1 - \alpha - \beta} \right) \ln (n + \delta + g) \]  

(26)

Equation (26) above shows that per capita income varies positively with the fraction of income invested in physical and human capital, and negatively with population growth. Partial differentiations of equation (26) gives

\[ \frac{\partial \ln y}{\partial \ln s_k} = \frac{\alpha}{1 - \alpha - \beta} > 0 \]

\[ \frac{\partial \ln y}{\partial \ln s_h} = \frac{\beta}{1 - \alpha - \beta} > 0 \]

\[ \frac{\partial \ln y}{\partial \ln (n + \delta + g)} = -\frac{\alpha + \beta}{1 - \alpha - \beta} < 0 \]

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42 See Appendix C for derivations.
43 See Appendix D.
The inequalities in equation (27) hold because \((\alpha + \beta < 1), (0 < \alpha < 1),\) and \(0 < \beta < 1)\). Hence, *ceteris paribus*, a 1% increase in saving rate devoted to physical or to human capital will increase per capita output by \(\left(\frac{\alpha}{1 - \alpha - \beta}\right)\)% or \(\left(\frac{\beta}{1 - \alpha - \beta}\right)\)% respectively.

The relationship described in equation (26) is however difficult to estimate because data for the rate \(s_h\) are not always readily available. Mankiw, Romer, and Weil (1992) substituted the steady state level of human capital \(h^*\) for the rate of saving allocated to investment in human capital \(s_h\). From equation (24b) we derive

\[
s_h = \left[ \frac{(n + \delta + g) h^* (1 - \alpha - \beta)}{s^a} \right] \frac{1}{(1 - \alpha)}
\]

Replacing \(s_h\) in equation (26) gives

\[
l_ny = \ln A_0 + gt + \left(\frac{\alpha}{1 - \alpha}\right) \ln s_k + \left(\frac{\beta}{1 - \alpha}\right) \ln h^* - \left(\frac{\alpha}{1 - \alpha}\right) \ln (n + \delta + g)
\]

\[\tag{29}\]

\(^{44}\)Secondary School Enrollment can be used as a proxy for the level of human capital.
Once again human capital will have a positive impact on per capita income as shown by the partial derivative of equation (29) with respect to \( h^* \), that is

\[
\frac{\partial \ln y}{\partial \ln h^*} = \frac{\beta}{1 - \alpha} > 0
\]

(30)

We conclude by reproducing below the three equations used for estimation purposes in chapter 5:

\[
\ln y = \frac{\alpha}{1 - \alpha} \ln s - \frac{\alpha}{1 - \alpha} \ln n
\]

(6)

\[
\ln y = \ln A_0 + gt + \frac{\alpha}{1 - \alpha} \ln s - \frac{\alpha}{1 - \alpha} \ln (\delta + n + g)
\]

(17)

\[
\ln y = \ln A_0 + gt + \left( \frac{\alpha}{1 - \alpha} \right) \ln s_k + \left( \frac{\beta}{1 - \alpha} \right) \ln h^* - \left( \frac{\alpha}{1 - \alpha} \right) \ln (n + \delta + g)
\]

(29)
CHAPTER 5
THE VARIABLES

In this chapter we briefly describe the data to be used for the empirical study. Section I describes the variables and their source. Section II discusses the methodology. Section III presents an overview of the variables used in the regressions and of scatter diagrams of the correlation between Per Capita GDP and each of the three independent variables.

I. Description and Source

The data were obtained from the Summers and Heston (1988) data set and from UNESCO's yearly reports. The annual series range from 1960 to 1985. We consider the following variables:

\[ \text{LGDP} = \text{Log of Per Capita GDP} \]
\[ \text{LINV} = \text{Log of Gross Domestic Investment as a percentage of GDP} \]
\[ \text{LPOP} = \text{Log of Population Growth Rate} \]
The lack of continuous series limited the study to 32 SSA countries. We consider a cross-sectional-cum-time-series data set of 827 observations.

II. Methodology

There are several ways to organize time-series-cum-cross-country data. The following two methods are particularly common:

(i) testing individual time series for each country, and

(ii) averaging each country’s series into one data point and estimating a single cross-sectional equation.

The first method is useful when looking at conditions that influence growth within individual countries over time because it makes use of all available data in the series. However, the presence of data gaps may pose problems concerning the reliability of the estimates.

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45 POP is augmented by .05 to account for depreciation and technology. Mankiw et al.’s assumption that (δ + g = .05) is based on studies that observed a value for depreciation of about .03 and for growth in per capita income of about 0.022.

46 See Appendix H for a list of SSA countries considered.

47 The statistical program used is MicroTSP version 7.0 by D. M. Lilien (1990).

The second method is based on averaged data. This averaging method is more appropriate for studying secular growth patterns because it purges the series of cyclical fluctuations.\textsuperscript{49} Thus it allows the coefficients to capture the basic growth relationships.

However, Grier and Tullock (1989) warn against the use of the averaging method over the entire period because of the risk of destroying information in the sample. Moreover, the method cannot be used if there is evidence of the presence of time-fixed or country-fixed effects, or both.

Kormendi and Meguire (1985) point out that the use of "decade, five-year, or even annual data" may allow for "more refined and potentially more powerful tests".\textsuperscript{50} Grier and Tullock (1989) also favor short span averages over the full period average.

In this study we consider disaggregated series as well as data averaged over five, ten and twenty-six years.\textsuperscript{51}

III. The Variables

In this section, we discuss briefly the movements observed in the relevant variables over the period under study. We examine the relationships between GDP

\textsuperscript{49}The averaging method was used by Kormendi and Meguire (1985) in their multi-variable study of economic growth.

\textsuperscript{50}See Grier and Tullock (1989).

\textsuperscript{51}The problem of nonstationarity associated with time series does not arise here since the variables used are expressed as rates (investment, saving, population growth) or ratios (per capita income, secondary school enrollment).
and the independent variables as portrayed in scatter diagrams.\textsuperscript{52} We also mention any problem involved in using some of the variables.

A. The Dependent Variable

The trend in the growth of GDP in SSA over the past decades has been a main cause for concern. In the 1980s, per capita income in SSA grew at an average rate of -2.6\% annually. This stands in sharp contrast with SSA's post-independence performance, when GDP grew at 2.0\% on average annually. Also, such performance contrasts with South Asia's over those three decades. In the late 1960s-early 1970s, South Asia was experiencing on average a 1.2\% growth in per capita income. Two decades later, its growth rate had increased to an annual average of 2.8\%.

However, it is worth noting that the per capita GDP growth experience in SSA has been varied at the individual country level. Between the 1960s and 1980s, Botswana's per capita GDP more than doubled, while Zaire's and Ghana's decreased by 31.9\% and 29.5\%, respectively. Gabon's average annual per capita GDP of $3152.67 in the 1980s contrasts with Tanzania's $332.83.\textsuperscript{53}

We now examine the movements in saving, population growth, and secondary school enrollment rates in SSA between the 1960s and 1980s.

\textsuperscript{52}See Appendix E for scatter plots for each decade.

\textsuperscript{53}Comparisons are based on averages of Summers and Heston's (1989) data.
B. The Independent Variables

The assumption of a closed economy in chapter 3 means that saving strictly equals investment. In fact, the trends in saving and investment in SSA over the period considered move in the same direction. Both saving and investment in SSA increased in the 1970s relative to their 1960s levels: saving rose from about 17% to about 19.4%, while investment rose from 15% to 20.6%. In the 1980s, they both fell relative to their 1970s levels: saving fell from about 19.4% to about 12.5%, while investment fell from 20.6% to 15.9%.

However, the "aggregate result conceals a wide variety of experiences among country groups" as well as within countries over time. For example, in the 1960s Burkina Faso experienced a negative saving rate while Zambia's was 43.97%. Mauritania's saving rate fell from 32.87% in the 1960s to 6.04% in the 1980s. Lesotho showed negative saving rates for the three decades considered, although investment rate was consistently positive over the same time span.

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54 The rates of saving and investment are percentages of GDP. The levels of saving and investment were higher in SSA than in South Asia in the early 1970s. See World Bank (1989).


56 The consistently negative saving rate in Lesotho may be related to the fact that a considerable portion of its labor force is temporarily employed in South Africa and transfers part of its income to Lesotho. See "Lesotho: A Development Challenge" World Bank Country Economic Report, 1975, p. 16-17. It appears that countries like Burkina Faso and Lesotho, two net exporters of labor, will experience negative saving rates because a portion of income spent on consumption may not be reported as earned income.
The specification of the Solow model requires the use of natural logarithms on all variables. The occurrence of negative saving rates would make the computation impossible. We therefore substitute gross domestic investment for saving when regressing our two models.\textsuperscript{57} The scatter plots in figure (4a) and figure (4b) show that both saving and investment are positively related to per capita GDP over the period considered. Thus, the substitution of investment for saving in the regressions will not severely alter the results.\textsuperscript{58} A positive coefficient on investment will be consistent with the predictions of the model.

\textsuperscript{57}See Appendix G for estimated coefficients when only positive saving rate is used, instead of investment rate. The empirical results based on saving rate are similar to regressions that use investment rate. Mankiw et al. (1992) also used Investment as a percentage of GDP in their regressions.

\textsuperscript{58}The correlation coefficient between investment and saving is .42 on average over the study period. For the 1960s, 1970s, and 1980s, the correlation coefficient was .60, .40, and .24, respectively.
Figure 4a: Per Capita GDP and Saving--1960-85

Figure 4b: Per Capita GDP and Investment--1960-85
The model also predicts a negative coefficient on population. Population growth rate in SSA has been rising continuously since independence.\textsuperscript{59} In the late 1960s-early 1970s, population grew at 2.6\% on average annually.\textsuperscript{60} In the late 1970s and the 1980s, the growth rate amounted to 2.8\% and 3.1\%, respectively.

The observed population increases in SSA occur despite claims of declining fertility rates. Although fertility rates fell by 26\% in Botswana, 35\% in Kenya, and 18\% in Zimbabwe,\textsuperscript{61} for example, these countries experienced population growth rates in excess of 2\% on average over the past three decades. This can be due in part to the growing number of women of reproductive age. It is argued that high fertility rates in the early 1960s resulted in a lagged increase in the number of women of childbearing age. Given persisting cultural patterns,\textsuperscript{62} this means that lower fertility rates do not necessarily result in lower population growth rates.\textsuperscript{63}

\textsuperscript{59}In absolute terms, Africa's population is not a concern, since the population density of SSA in 1987 was 21 persons per square kilometers compared with South Asia's 210, East Asia's 108, and Europe's 34. (See World Development Report 1989). In fact, Odedokun (1993) found that population size promotes growth in Africa. However, relative to GDF growth and resource base, population growth in SSA poses a severe living standard problem.

\textsuperscript{60}World Bank (1989), Sub-Saharan Africa-From Crisis to Sustainable Growth, p 26.

\textsuperscript{61}See Robey et al. (1993).

\textsuperscript{62}Cultural patterns affect, for example, the age at marriage of women, the number of spouses.

\textsuperscript{63}It is also necessary to look at the movement in birth and death rates: there was a notable fall in the death rate in SSA between 1965 and 1987, while the fall in the birth rate during that same period was minor. Moreover, infant mortality rates for 1965, 1975, and 1987 displayed a downward trend in low-income and middle-income economies. See World Bank (1989), World Development Report.
SSA's steadily growing population adds more and more people to its pool of workers. Relative to resource base, population growth leads to a fall in the marginal productivity of labor. Hence, per capita output fall. As shown in figure (5), there is a negative relationship between population growth and per capita GDP in SSA over the 1960-80 period.
Figure 5: Per Capita GDP and Population Growth–1960-85
The third model of this study analyses the impact of investment in human capital. The concept of human capital is related to changes in the quality of labor. Secondary school enrollment is generally used as a measure of the quality of manpower. However, even when data on enrollment in secondary education is available, caution must be taken in its use. Schultz (1988) warns that the impact of education on productivity is based on "populations in which educational attainment is not randomized but is itself an economic choice variable." Moreover, a measure of the concept of human capital is not comparable to a measure of physical capital because of the particular features of the former. Schultz lists four of those features. First, property rights apply differently to human capital and to physical capital. Second, worker preferences are involved in human capital. Third, non-marketable goods are affected by education but are not measurable. And finally, welfare effects arise because the benefit of an improvement in human capital is shared by the community.

Enrollment in secondary education in SSA improved from 4% in 1965 to 16% in 1986. This movement was similar to the trend in secondary education worldwide over that same period. Moreover, Africa (along with East Asia) was considered

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65Ibid

66The numbers refer to the percentage of people within the secondary schooling age group actually enrolled in secondary education. The measure of enrollment is weighted according to each country’s share in SSA population. See World Development Report (1989).
among the "overachievers," in contrast with South Asia, West Asia, and Latin America, where investment in education was lower than expected.67

The augmented model predicts a positive coefficient on schooling. The scatter diagram in figure (6) shows that schooling is positively related to per capita GDP in SSA between the 1960s and 1980s.

Figure 6: Per Capita GDP and Schooling--1960-85
CHAPTER 6
ESTIMATION PROCEDURE AND RESULTS

In this chapter we discuss the empirical results. The basic Solow predictions are tested in Model 1 which is based on equation (6) of chapter 3. Model 2 augments population by 0.05 to account for depreciation and technology. The effect of human capital is tested in Model 3 which is based on the augmented equation (29) of chapter 4.

\[ LGDP = \text{CONSTANT} + \alpha_1 \text{LINV} - \alpha_2 \text{LPOP} \]  
(Model 1)

\[ LGDP = \text{CONSTANT} + \beta_1 \text{LINV} - \beta_2 \text{LPGD} \]  
(Model 2)

\[ LGDP = \text{CONSTANT} + \gamma_1 \text{LINV} - \gamma_2 \text{LPGD} + \gamma_3 \text{LSEC} \]  
(Model 3)

Positive coefficients on LINV and LSEC would be consistent with Solow's predictions and with Mankiw et al.'s (1992) results. The basic Solow model also predicts a negative coefficient on LPOP. Model 1 and Model 2 appear in Tables 1 and 2, respectively. They each consist of four regressions of differing levels of aggregation.\(^8\) The first regression pools the 32 African countries over a period of

\(^8\)We regressed dummy variables to test for shifts over time and across countries. The results showed no shift in the intercept due to time. Country dummies for only Liberia, Togo, and Zambia were not significant. However, LPOP was positive and significant in the latter regression.
26 years. The second regression pools three decadal averages for each of the 32 countries, amounting to 96 observations. The third regression of 160 is a pooling of five quinary averages per country. The fourth regression uses 827 observations, being a panel of 26 annual data points for the 32 countries.

Model 3 is shown in Table 3. It is tested using three regressions similar to the first three used in Models 1 and 2. Due to unavailability of continuous data on secondary school enrollment in SSA over the period studied, it was not possible to perform regression using annual panel data.

We observe that the significance of the variables improves with the level of disaggregation. Both investment and secondary school enrollment are significant at 1% level in their respective regressions. Population growth is significant at 1% level only in the fourth regression of Model 1 (when n = 825). Augmented population growth is significant at 10% level in Model 2 only when n = 825.

The inclusion of secondary school enrollment, the proxy for human capital, improves the significance of the augmented population growth variable slightly, such

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69 We use one data point per country.
70 Data for Burkina Faso ranges from 1965 to 1985.
71 Initial regressions of individual country data yielded no meaningful pattern. Regressions using averages for the 1960s, 1970s, and 1980s, respectively showed that investment was always positive and significant. However, population was never significant and was of the wrong sign in the 1980s.
72 This is compatible with arguments by Grier and Tullock: they warn that highly aggregated series result in the loss of information generally present in raw data.
that the latter becomes significant at 10% level when \( n = 160 \) (in Model 3). However, when human capital is accounted for, the importance of physical capital declines. The overestimation of the investment coefficient in Models 1 and 2 implies that physical capital and human capital are positively correlated. Also, we note that the coefficient of determination (\( R^2 \)) in Models 1 and 2 falls as the data becomes more disaggregated and the number of observations increases.

The sign on investment is consistent with the basic Solow prediction, with Mankiw et al.'s (1992) results and with other empirical literature on economic growth. Our results show that, in the case of SSA, saving has a significantly positive impact on per capita GDP, in accordance with the findings of Knight et al. (1993). Although the negative impact of population growth is compatible with the

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73 This observation seems compatible with Azariadis and Drazen (1990) who point out that the omission of a human capital variable may lead to a specification bias.

74 The coefficient on LINV in the first three regressions is smaller in Model 3 than in Models 1 and 2. The inclusion of secondary school enrollment in Mankiw et al.'s regressions reduces the coefficient on investment.

75 This may be due to increased variation in the dependent variable as the sample size increases from averaged decadal or quinary variations to annual variations.

76 When setting up the basic Solow model in chapter 3, we assumed that saving equals investment.

77 The coefficients are not stable over the time span considered: the size of the coefficients differs across each five-year period.
above-mentioned work, it is not consistently significant throughout our results. Secondary school enrollment has a significantly positive impact on per capita GDP. Landau (1983) found that investment in education was positive and significant at 1% level in cross-country regressions. Also, in Otani and Villanueva's (1990) cross-country regressions, "Budgetary share of expenditure on human capital" was positive and significant at 10% level.

According to our results, education and high saving tend to promote growth. This is consistent with Lucas' (1993) observation that "miracle economies" are characterized by an increasingly well-educated population and a high saving rate among other features.

Although our models are similar in structure to Mankiw et al.'s (1992), there are nonetheless differences between the two studies. On the one hand, Mankiw et al.'s (1992) results are based on a heterogeneous sample of developed and developing countries. In contrast, our work focuses on a particular group of developing countries: Sub-Saharan Africa. On the other hand, Mankiw et al. (1992) use cross-sectional data in their regressions, while the major portion of our findings is based on data that

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The decrease in significance when population growth is augmented may imply that the obsolescence effect on labor of technological progress does not hold for SSA.
In conclusion, we have shown that Solow's predictions that saving has a positive effect and population growth has a negative effect on per capita income hold for SSA over the period studied. Investment and Secondary school enrollment are consistently significant, whereas Population growth is significant only when a large number of observations is used or when the model is augmented. Regressions using the most disaggregate data set improve the significance of the variables. The results are consistent with existing empirical literature on economic growth.
TABLE 1
MODEL 1: ESTIMATING THE BASIC SOLOW MODEL

Dependent Variable: log GDP per capita

<table>
<thead>
<tr>
<th></th>
<th>I</th>
<th>II</th>
<th>III</th>
<th>IV</th>
</tr>
</thead>
<tbody>
<tr>
<td>CONSTANT</td>
<td>4.996</td>
<td>5.084</td>
<td>5.255</td>
<td>5.374</td>
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<td></td>
<td>(11.34)</td>
<td>(21.78)</td>
<td>(31.45)</td>
<td>(75.30)</td>
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<tr>
<td>LINV</td>
<td>0.635***</td>
<td>0.552***</td>
<td>0.492***</td>
<td>0.438***</td>
</tr>
<tr>
<td></td>
<td>(4.15)**</td>
<td>(6.61)**</td>
<td>(8.28)**</td>
<td>(17.28)**</td>
</tr>
<tr>
<td>LPOP</td>
<td>-0.317 (-1.05)</td>
<td>-0.171 (-1.12)</td>
<td>-0.202 (-1.78)*</td>
<td>-0.172 (-3.72)**</td>
</tr>
<tr>
<td>R²</td>
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</tr>
<tr>
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<td>21.92</td>
<td>34.32</td>
<td>149.29</td>
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<tr>
<td>n</td>
<td>32</td>
<td>96</td>
<td>160</td>
<td>825</td>
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</table>

*** Significant at 1% level
** Significant at 5% level
* Significant at 10% level
**TABLE 2**

**MODEL 2: THE SOLOW MODEL WITH TECHNOLOGY AND DEPRECIATION**

Dependent Variable: log GDP per capita

<table>
<thead>
<tr>
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<th>IV</th>
</tr>
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<td>(5.77)</td>
<td>(8.26)</td>
<td>(19.92)</td>
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<td><strong>LINV</strong></td>
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<td>0.483</td>
<td>0.430</td>
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<tr>
<td></td>
<td>(4.08)**</td>
<td>(6.39)**</td>
<td>(8.02)**</td>
<td>(16.77)**</td>
</tr>
<tr>
<td><strong>LPGD</strong></td>
<td>-0.767</td>
<td>-0.252</td>
<td>-0.356</td>
<td>-0.279</td>
</tr>
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<td>(-0.85)</td>
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<td><strong>R²</strong></td>
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<td>160</td>
<td>825</td>
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</table>

*** Significant at 1% level
** Significant at 5% level
* Significant at 10% level
### TABLE 3

**MODEL 3: ESTIMATING THE AUGMENTED SOLOW MODEL**

Dependent Variable: log GDP per capita

<table>
<thead>
<tr>
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<th>III</th>
</tr>
</thead>
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<tr>
<td></td>
<td>(4.25)</td>
<td>(7.39)</td>
<td>(10.63)</td>
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<td><strong>LINV</strong></td>
<td>0.421</td>
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<td>0.314</td>
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<tr>
<td></td>
<td>(3.36)***</td>
<td>(5.16)***</td>
<td>(6.17)***</td>
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<td><strong>LPGD</strong></td>
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<td>-0.505</td>
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<td>(-1.78)*</td>
</tr>
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<td><strong>LSEC</strong></td>
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<td>0.291</td>
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<tr>
<td></td>
<td>(4.74)***</td>
<td>(6.88)***</td>
<td>(9.65)***</td>
</tr>
<tr>
<td><strong>R²</strong></td>
<td>0.648</td>
<td>0.546</td>
<td>0.558</td>
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<td><strong>sse</strong></td>
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<td>11.29</td>
<td>17.71</td>
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<tr>
<td><strong>F-stat</strong></td>
<td>17.19</td>
<td>36.94</td>
<td>65.73</td>
</tr>
<tr>
<td><strong>n</strong></td>
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<td>160</td>
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*** Significant at 1% level  
** Significant at 5% level  
* Significant at 10% level
CHAPTER 7
CONCLUSION

In this study we have examined whether Solow's predictions about the role of saving and population growth in the determination of per capita income hold for Sub-Saharan Africa (SSA). Our work was prompted by the growing concern over the poor economic performance of SSA relative to the rest of the world over the past decades.

We used Mankiw et al.'s (1992) version of Solow's model to estimate pooled cross-sectional-cum-time-series regressions on 32 SSA countries. Our results are consistent with those obtained by Mankiw et al. (1992) and by Knight et al. (1993). We found that, in the case of SSA, saving has a positive and significant impact on per capita income. The impact of population growth on per capita income was consistently negative, though significant only when the most disaggregate data was used or when human capital was included. This population growth behavior is compatible with arguments by Grier and Tullock (1989) and by Azariadis and Drazen (1990).

Given the crucial assumptions of (i) variable factor proportions in a linearly homogeneous production function, (ii) a closed economy, and (iii) equality between
saving and investment, steady state occurs. While the Solow model predicts the
direction of the impact of saving and of population growth, the long-run steady-state
phenomenon does not account for the observed growth slowdown. However, based
on our results, shifts in steady states—arising from the upward trend in population
growth and the downward trend in saving observed in SSA—have exerted a
continuous downward pressure on that region’s per capita GDP.

Hence, it appears that investment in physical capital and in human capital are
the most effective policy channels available to SSA to reverse the downward trend
in per capita income. In fact, we found that saving rate and secondary school
enrollment ratio are significant promoters of per capita income.

While panel results were according to expectations, estimations and
predictions using country time series suggested presence of misspecification errors.
However, it may be very difficult to address the latter issue in view of data
availability problems.

An extension to this work will involve comparisons between SSA and other
groups of developing countries. Particularly, it would be interesting to see how well
the Solow predictions fit more narrowly defined groups of countries such as Latin
America and Caribbean countries or South and East Asia. The results may provide
insight to the disparity between group and individual country performances observed
in this study.
APPENDICES
APPENDIX A
DERIVATIONS FOR THE BASIC SOLOW MODEL

We use equation (7) of chapter 3 to derive the basic relationship implied by the Solow model. In chapter 3 we obtained the path of capital formation

\[ \dot{k} = s f(k) - kn \]. Under steady state, \( \dot{k} = 0 \) and

\[ s f(k) = kn \] (3)

Based on equation (2) of chapter 4 that \( y = f(k) = k^a \), we rewrite equation (3) as

\[ s k^a = kn \]

\[ k = \left( \frac{s}{n} \right)^{\frac{1}{1-a}} \] (4)

Substituting the finding into the Cobb-Douglas function gives

\[ y = k^a = \left( \frac{s}{n} \right)^{\frac{a}{1-a}} \] (5)

Taking natural logarithms on both sides of equation (5) results in

\[ \ln y = \frac{a}{1-a} \ln s - \frac{a}{1-a} \ln n \] (6)
APPENDIX B

INCORPORATING TECHNOLOGY AND DEPRECIATION

When technology and depreciation are accounted for, the time path of capital formation is given by

\[ \frac{dK}{dt} = \dot{K} = sY - \delta K \]

\[ \frac{dK}{dt} = \dot{K} = sF(K, AL) - \delta K \]

\[ \frac{dK}{dt} = sF(K, A_0 L_0 e^{(n+\delta)}) - \delta K \] (11)

We let \( k = \frac{K}{AL} \) or \( K = kL_0A_0e^{(n+\delta)} \) which, differentiated totally gives

\[ \frac{dk}{dt} = \left[ \frac{dk}{dt} + k[n + g] \right]L_0A_0e^{(n+\delta)} \] (12)

Equating equations (11) and (12) and solving gives

\[ \frac{dk}{dt} = sf(k) - k[\delta + n + g] \] (13)

59
Recalling that under steady state $\dot{k} = 0$, equation (13) becomes

$$sf(k) = fc[\delta + n + g]$$

(14)

Since $f(k) = k^a$, we rearrange equation (14) as

$$sk^a = k[\delta + n + g]$$

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

(15)

From equation (8) of chapter 4 we have $\frac{Y}{AL} = f(k) = k^a$ or $\frac{Y}{L} = Ak^a$. Therefore

$$\frac{Y}{L} = A_0e^{gt}\left[\frac{s}{(\delta + n + g)}\right]^{\frac{a}{1-a}}$$

(16)

Taking natural logarithms on both sides of equation (16) gives

$$\ln y = \ln A_0 + gt + \frac{a}{1-a}\ln s - \frac{a}{1-a}\ln(\delta + n + g)$$

(17)
Given changes in physical and human capital stock as

\[
\frac{dK}{dt} = I_k = s_k Y - \delta K \tag{21a}
\]

\[
\frac{dH}{dt} = I_h = s_h Y - \delta H \tag{21b}
\]

We can rewrite \( k = \frac{K}{AL} \) and \( h = \frac{H}{AL} \) from equation (20) of chapter 4 as

\[ K = k AL \quad \text{and} \quad H = h AL \]

respectively, which differentiated totally gives:

\[
\frac{dK}{dt} = k[n + g]A_t L_t + \frac{dk}{dt} A_t L_t \tag{22a}
\]

\[
\frac{dH}{dt} = h[n + g]A_t L_t + \frac{dh}{dt} A_t L_t \tag{22b}
\]

Since under steady state \( \dot{k} = 0 \), equating equations (21a) and (22a) results in
which can be simplified to

\[ k = \left[ \frac{s_k^{(1-\beta)} s_h^{\beta}}{n + \delta + g} \right] \frac{1}{(1 - \alpha - \beta)} \]  \quad (24a)

Similarly, under steady state \( \dot{h} = 0 \); therefore, equating equations (21b) and (22b) results in

\[ s_h k^a h^\beta = h(n + \delta + g) \]  \quad (23b)

which can be simplified to

\[ h = \left[ \frac{s_k^a s_h^{(1-a)}}{n + \delta + g} \right] \frac{1}{(1 - \alpha - \beta)} \]  \quad (24b)

---

\textsuperscript{60} We note that equations (23a) and (23b) are equivalent:

\[ \frac{k}{s_k k^a h^\beta} = \frac{1}{(n + \delta + g)} = \frac{h}{s_h k^a h^\beta} \]
APPENDIX D
DERIVING THE AUGMENTED SOLOW MODEL

In appendix C we saw the relationship between physical and human capital and the rates of saving and population growth. The effect on per capita income can be examined by replacing equations (24a) and (24b) into equation (20) of chapter 4 as follows:

\[ y = f \left( \frac{s_k^{(1-\beta)} s_h^{\beta}}{n + \delta + g}, \frac{s_k^\alpha s_h^{(1-\alpha)}}{n + \delta + g} \right) \]

such that

\[ \frac{Y}{AL} = \left( \frac{s_k^{(1-\beta)} s_h^{\beta}}{n + \delta + g} \right)^{\alpha} \cdot \left( \frac{s_k^\alpha s_h^{(1-\alpha)}}{n + \delta + g} \right)^{\beta} \]

and

\[ y = A_0 e^{gt} \cdot \left( \frac{s_k^{(1-\beta)} s_h^{\beta}}{n + \delta + g} \right)^{\alpha} \cdot \left( \frac{s_k^\alpha s_h^{(1-\alpha)}}{n + \delta + g} \right)^{\beta} \] (25)

Taking natural logarithms on both sides and simplifying gives:

\[ \ln y = \ln A_0 + gt + \left( \frac{\alpha}{1-\alpha-\beta} \right) \ln s_k + \left( \frac{\beta}{1-\alpha-\beta} \right) \ln s_h - \left( \frac{\alpha + \beta}{1-\alpha-\beta} \right) \ln (n + \delta + g) \] (26)
APPENDIX E

RELATIONSHIPS BETWEEN THE INDEPENDENT VARIABLES
AND PER CAPITA GDP

The scatter diagrams for the 1960s, 1970s, and 1980s show the relationship between per capita GDP and saving, investment, schooling, and population growth separately.

As expected, there is a consistently positive relationship between per capita GDP and saving, investment, schooling, and population growth for each decade.

The scatter plots show an expected negative relationship between per capita GDP and population growth for the 1960s and 1970s. The positive fit shown for the 1980s may be related to major economic and political disturbances in SSA in that decade.
Per Capita GDP and Saving--1960s

Per Capita GDP and Saving--1970s

Per Capita GDP and Saving--1980s
APPENDIX F
PREDICTIONS OF THE MODELS

We use coefficients estimated by the basic Solow model (Model 1) and by Mankiw et al.’s version of the Solow model (Model 2) to calculate the estimated growth rate of per capita income for Burkina Faso, Congo, Madagascar, Mauritius, and Togo in 1980 and 1985. These countries were chosen because time series regressions using their individual data yielded expected signs on the coefficients.

Population growth rate is augmented by 0.05 in Model 2 to account for technology and depreciation. The estimated growth rates differ from the actual growth rates. In some cases where the rates are of relatively similar magnitude, the signs differ.
PREDICTIONS BASED ON THE BASIC SOLOW MODEL

Growth Rates for 1980 and 1985

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<th>ACTUAL</th>
<th>ESTIMATE</th>
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PREDICTIONS BASED ON MANKIW ET AL.'S VERSION OF SOLOW'S MODEL

Growth Rates for 1980 and 1985

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<td>77.34</td>
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APPENDIX G
SAVING AS AN INDEPENDENT VARIABLE

The following are regression results when the log of saving rate is used and countries showing negative saving rates are excluded. Unavailability of data precludes estimations with larger samples. We report results comparable with regressions I and II of Model 1.

Dependent Variable: log GDP per capita

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<th></th>
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<td>6.027</td>
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<td>(18.79)</td>
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<td>(5.81)***</td>
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*** Significant at 1% level
**  Significant at 5% level
*   Significant at 10% level
APPENDIX H

LIST OF SSA COUNTRIES CONSIDERED

The following SSA countries were included in this study:

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<th>Burkina Faso</th>
</tr>
</thead>
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BIBLIOGRAPHY


