March 2004

Explaining Economic Growth: Factor Accumulation, Total Factor Productivity Growth, and Production Efficiency Improvement

Yasmina Reem Limam
COMETE-Engineering, Tunis

Stephen M. Miller
University of Nevada, Las Vegas, and University of Connecticut

Recommended Citation
Limam, Yasmina Reem and Miller, Stephen M., "Explaining Economic Growth: Factor Accumulation, Total Factor Productivity Growth, and Production Efficiency Improvement" (2004). *Economics Working Papers*. 200420.
https://opencommons.uconn.edu/econ_wpapers/200420

Forthcoming in Quarterly Review of Economics and Finance

Explaining Economic Growth: Factor Accumulation, Total Factor Productivity Growth, and Production Efficiency Improvement

Yasmina Reem Limam
COMETE-Engineering, Tunis

Stephen M. Miller
University of Nevada, Las Vegas, and University of Connecticut

Working Paper 2004-20

March 2004

341 Mansfield Road, Unit 1063
Storrs, CT 06269–1063
Phone: (860) 486–3022
Fax: (860) 486–4463
http://www.econ.uconn.edu/

Abstract

This paper examines cross-country patterns of economic growth by estimating a stochastic frontier production function for 80 developed and developing countries and decomposing output change into factor accumulation, total factor productivity growth, and production efficiency improvement. In addition, this paper incorporates the quality of inputs in analyzing output growth, where the productivity of capital depends on its average age, while the productivity of labor depends on its average level of education. Our growth decomposition involves five geographic regions - Africa, East Asian, Latin America, South Asia, and the West. Factor growth, especially capital accumulation, generally proves much more important than either the improved quality of factors or total factor productivity growth in explaining output growth. The quality of capital positively and significantly affects output growth in all groups. The quality of labor, however, only possesses a positive and significant effect on output growth in Africa, East Asia, and the West. Labor quality owns a negative and significant effect in Latin America and South Asia.

Journal of Economic Literature Classification: F43, O47

Keywords: Productivity; Efficiency; Growth Accounting

I. Introduction

Countries experience marked differences in the development of their productive capacities and in the improvement of their standards of living. While some countries achieve rapid growth of income and high standards of living, others remain mired at a level of development that does not assure the subsistence needs of the population. Several theoretical models explain the growth rate of a country's real GDP per capita. Dispute still exists, however, concerning the most important determinants of economic growth. While some think that physical capital accumulation plays the dominant role, others argue that growth in total factor productivity (TFP) provides the dominant source of output growth.

Building on the original work of the fixed-factor proportions model of Harrod (1939) and Domar (1946) and the dual-sector model of Lewis (1954), Solow (1956) presents a simplified model of economic growth that serves as the point of departure for most later growth theories. The model specifies a neoclassical production function, where physical capital, labor, and an exogenous technology influence the level of output. Estimates show for a sample of developed countries that the model leaves a large unexplained residual, suggesting that capital and labor explain only a fraction of per capita output growth. Growth accounting analysis generally assumes that the Solow residual captures total factor productivity (TFP) growth.

A major criticism of the neoclassical growth model comes from its failure to explain cross-country differences in per capita growth rates. Even after accounting for human capital accumulation, a growing body of research suggests that something other than capital, labor, and human capital accounts for the bulk of the observed differences between countries in the level and growth rate of real gross domestic product. The failure of the neoclassical model adequately to explain output growth opens the door for models that focus on analyzing the sources of TFP growth, so called endogenous growth models (Romer, 1986; Lucas, 1988).

Advocates of endogenous growth theory claim that physical capital growth alone cannot explain per capita output growth and that the neoclassical model fails to capture a number of crucial variables that explain economic growth. They argue that the large Solow residual responds to variables that are endogenous to the model (e.g., endogenous technology and human capital accumulation). Their main contributions consist of including not only human capital (Romer, 1986, 1990, 1994; Barro, 1991; Lucas, 1988), but also international trade in goods (Feenstra, 1996; Eaton and Kortum, 1995, 1996; Rivera Batiz and Romer, 1991a, 1991b; Pissarides, 1997; Grossman and Helpman, 1991). By incorporating technological change, those models consider the diffusion of technology between countries, and the ability of developing countries to adopt and implement foreign technology.

This paper improves our understanding of cross-country patterns of economic growth by estimating a stochastic frontier production function for a sample of 80 developed and developing countries and decomposing output change into factor accumulation, total factor productivity growth, and production efficiency improvement.

The analysis differs from previous studies in at least three respects. First, most studies consider factor accumulation and total factor productivity growth, implicitly assuming that the production process does not involve the inefficient use of factors of production. We add this third dimension, production efficiency improvement, to the existing explanations of economic growth.

Second, because of data limitations in developing countries, most growth studies consider developed countries. Recent growth models look at the diffusion of technology and the capacity of developing countries to use and assimilate technology (Keller, 1996; Parente and

Prescot, 1994, Barro and Sala-i-Martin, 1995; Basu and Veil, 1998). Consequently, a study of output growth that incorporates developing countries necessarily captures the mechanisms of technology diffusion and assimilation. Specifically, this paper calculates a consistent capital stock series for 104 countries (among which 60 are developing countries) covering a thirty-year period from 1960 to 1989, using the techniques of King and Levine (1994).

Third, this paper incorporates the quality of inputs in analyzing output growth. Ignoring the quality of inputs imposes the strong assumption that inputs are homogenous no matter the time of their construction or their level of education. To account for differences in the quality of capital and labor between countries, we assume that the productivity of capital depends on the average age of the capital stock, while the productivity of labor depends on the average level of education of the population. We calculate the average age of physical capital following Gapinski (1999) for 104 countries.[1]

Our conclusions include the following. The decomposition of output growth demonstrates that factor growth generally proves much more important than either the improved quality of factors or total factor productivity growth in explaining output growth. The quality of capital positively and significantly affects output growth in all groups. The quality of labor, however, only possesses a positive and significant effect on output growth in Africa, East Asia, and the West. Labor quality owns a negative and significant effect in Latin America and South

---

[1] Some empirical studies include the quality of human capital (education) as a separate factor of production (Barro, 1991, Miller and Upadhyah, 2000), while others treat human capital as augmenting labor (Koop, Oscewalski, and Steel, 2000, Tallman and Wang, 1994) and obtain a new measure of labor that they call "effective labor". Instead of building an "efficient labor" index, we assume that human capital directly affects the productivity of labor through the labor elasticity. While some studies correct for the quality of labor, fewer studies also correct for the quality of the capital stock, since measures for the quality of the capital stock do not exist. Koop, Oscewalski, and Steel, (2000) use the allocation of the labor force between sectors of the economy to augment capital. We use the average age of capital to account for the quality of the capital stock. Gapinski (1996a, 1996b) uses the average age of physical capital to analyze the contribution of physical capital to growth. Similar to labor quality, we assume that the quality of capital affects the productivity of capital directly through the capital elasticity.

Asia. Finally, fast economic growth associates with declining technical efficiency, and vice versa.

II. Review of Relevant Literature

The theory of economic growth considers how models offer different, but related, explanations of the process of growth. The major questions include the following: (i) Why do some countries grow faster than others and (ii) what are the most important components of output growth?

Solow (1956) develops a production function with substitutability between factors of production, modeling output growth as a function of capital, labor, and knowledge. Knowledge or technology is Harrod neutral, since it only affects the productivity of labor. The model assumes an exogenous and homogenous technology across countries. As countries accumulate technology at the same rate, cross-country differences in output growth rates represent differences in capital accumulation. The model also implies that a country's real GDP per capita growth negatively correlates with its initial level of income, that is, the convergence hypothesis.

Economists use growth accounting analysis to test empirically the neoclassical growth theory, and to evaluate the effect of physical capital accumulation on output growth. The results of the early growth accounting exercises raise questions about the role of capital accumulation in output growth. The large unexplained residual in Solow-model calculations suggests that capital and labor accumulation do not fully explain output growth.

Consequently, by emphasizing factor accumulation, the neoclassical model neglects differences in productivity growth and technological change captured by the large residual. In addition to its inability to explain cross-country real GDP per capita differences, and the failure of the convergence hypothesis, the neoclassical model also fails to explain the differences in real rates of returns on capital (Mankiw, 1995). By defining capital to include physical and human capital, Mankiw finds that the results more closely resemble the theoretical prediction of the neoclassical model. The works of Barro and Sala-i-Martin (1992, 1995), Mankiw, Romer, and Weil (1992) argue from a similar perspective.

Easterly and Levine (2001) identify four stylized facts, suggesting that growth economists should focus on TFP and its determinants rather than factor accumulation. First, much of the empirical evidence accumulated to date indicates that factor accumulation explains only a portion of the observed cross-country output growth.[2] Second, Easterly and Levine (2001) argue that increasing divergence rather than convergence in per capita income levels occurs, which emphasizes TFP with increasing returns to technology. Third, time-series data show that physical capital accumulation persists over time and in most countries while per capita output growth does not persist. This fact suggests that models of steady-state growth (such as the Solow model) may fit the experience of the United States and other developed countries, but will not fit the experiences of many developing countries. Finally, a tendency exists for the factors of production to "fly" to the same places, which causes an increased concentration of economic activity. In such circumstances, it is more appropriate to use models with technological complementarities rather than the neoclassical model with homogenous technology. Renewed interest in productivity as a source of output growth leads to the development of new methods for the decomposition of output growth into input and productivity growth.

Endogenous growth theory, initiated by Romer (1986) and Lucas (1988), departs from neoclassical theory and focuses on explaining the Solow residual. The theory considers the effects of variables such as trade, human capital, and endogenous technology on output growth,

---

[2] When analyzing output growth in a group of developed countries, Solow (1956) himself finds that capital accumulation explains only between one-eighth and one-fourth of income growth while the rest is explained by productivity growth.

and the different mechanisms of technology diffusion. Technological change becomes endogenous to the model and output growth becomes the outcome of forces that belong to the model. The "technological leader" countries generate technology (or knowledge). Technology diffuses through the trade of goods to the "follower" countries. Developed countries devote natural resources and human capital to invent new technology, while developing countries invest in human capital and their political and economic institutions to foster the diffusion and absorption of foreign technology.

As a result, the sources of TFP growth differ between developed and developing countries. Technological innovations provide the main source of TFP growth in advanced countries. Developing countries face the challenge of acquiring and absorbing foreign technology. In these countries, productivity growth depends on making the best use of the imported technology. These two components of TFP growth, innovation and absorption, determine cross-country differences in per capita income growth rates.[3]

The evidence that countries catch-up in TFP, but not in per capita income, reflects the findings of several empirical studies. Benhabib and Spiegel (1994) construct capital stocks for 133 countries, and assume a standard growth accounting decomposition with labor, physical capital, and human capital as inputs into production. They discover evidence of convergence in TFP. While labor and physical capital accumulation positively affect output growth, the coefficient on human capital is negative, but insignificant. The failure of human capital to explain output growth provides a surprise, since most governments dedicate tremendous effort

---

[3] Several studies link the remarkable growth of the East Asian countries during the 1960-1985 period to their prolonged growth of exports. Young (1994) argues that the results reflect the measure of output growth used. If measures of output per worker instead of output per capita measure output growth, the growth of East Asian countries is less spectacular and less differentiated from the rest of the sample.

and resources to educate their citizens.

Those results lead Benhabib and Spiegel (1994) to suspect that simply including human capital as an additional input leads to model misspecification. Rather, they suggest that human capital affects TFP growth through the adoption and implementation of new technologies. They present a model where they decompose TFP growth into two separate components: a catch-up term and a technological change component. Instead of including human capital as an input in production, however, the authors suggest that human capital affects income indirectly through its effect on TFP.

Fare et al. (1994) use Data Envelopment Analysis (DEA) to decompose total output growth into technical change and efficiency change in developed countries. The sample covers 17 OECD countries from 1978 to 1988. The authors construct a deterministic frontier for the sample, and compare each country's distance from the frontier in the constant returns to scale framework. The authors use distance functions to calculate the Malmquist index as an alternative measure of TFP. The Malmquist index isolates the changes in efficiency, interpreted as "catching-up" from technological change that is measured by shifts in the frontier. The efficiency factor further decomposes into pure technical efficiency change and changes in scale efficiency.

Henderson and Russell (2001) employ deterministic production frontiers to analyze macroeconomic convergence. Inspired by the recent work on endogenous growth theory, the authors include human capital in the analysis, and augment labor using the rate of return on education. The authors decompose labor productivity growth, and compare efficiency measurement in the models with and without human capital. With human capital, productivity growth decomposes into efficiency change, technological change, physical capital accumulation, and human capital accumulation. Henderson and Russel (2001) show that the increase in mean productivity reflects human capital accumulation. Finally, the study shows that technological change is non-neutral when changes take place in countries with high capital intensity.

Koop, Osiewalski, and Steel (1999) use a stochastic frontier model with Bayesian analysis to decompose output growth into input change, technological change, and efficiency change for a group of OECD countries. They assume that technological change differs across countries, and affects the marginal product of capital and labor. This specification of technological change represents a deviation from the cross-country and panel-data growth regression literature, where technological change is usually disembodied and the same for all countries. The authors extend Fare et al. (1994) and relax the assumption of completely independent frontiers over time.

A more recent paper by Koop et al (2000) extends the stochastic frontier analysis to a sample of developed and developing countries. Because of the heterogeneity of the countries in the sample, however, the authors assume that input quality does not compare across the set of countries, and they correct for variables using efficiency units of capital and labor. Labor in different countries has different levels of skills. Consequently, to correct for labor, the authors use the years of schooling embodied in the work force. The authors use two variables to correct physical capital, the percentage of the labor force in agriculture, and the percentage of the labor force in industry. The study decomposes TFP growth, and considers the effect of economic and institutional variables on technical efficiency. Regarding the factors correcting for labor, the education variable positively affects the productivity of labor. For capital, more industrialized countries exhibit higher productivity of capital. The growth decomposition analysis shows that in all groups, input growth contributes the most to output growth. Technological progress proves important in East Asia, however, where it accounts for about half of output growth over time. In Africa and the West, technological progress accounts respectively for 17 and 30 percent of total output growth. Latin America, however, experiences technological regress over the period.

III. Calculation of the Capital Stock and Its Average Age

This section estimates capital stocks for developed and developing countries from 1960 to 1989. Availability of information on human capital ultimately restricts our analysis to 80 countries, but we, nevertheless, calculate physical capital stock series for 104 countries. By covering a larger number of developing countries, such series allows the study of the relationship between physical capital accumulation and output growth for countries at different levels of development. Whenever possible, we compare our estimated capital stock series to those calculated by Benhabib and Spiegel (1994), King and Levine (1994), and to the Penn World Tables (PWT 5.6, and PWT 5). Calculating capital stocks for 104 countries facilitates such comparisons. Finally, this section also calculates the average age of physical capital.

We adopt the perpetual inventory method with the steady-state initial capital stock (King and Levine, 1994) to determine the capital stocks for 104 countries and over the thirty-year period 1960-89. First, we estimate the initial capital stock (1960) for each country. Then, based on that starting value, we use investment series with the perpetual inventory method to derive the capital stocks for the entire period.

To calculate an initial capital-stock value, we use the steady-state method (King and Levine, 1994). The method assumes that the capital-output ratio is constant in the steady state. That is, physical capital and real output grow at the same rate $\gamma_t^* = dK_t / K_t = dY_t / Y_t$, where γ_t^* is the steady-state growth of country j, K_t is the capital stock, and Y_t is real gross domestic product (GDP). Since $dK_t = I_t - \delta K_t$, then $(dK_t / K_t) = (I_t / K_t) - \delta$, where I_t is gross investment, and δ is the depreciation rate of physical capital.

Following King and Levine (1994), we assume that δ is constant across countries and time at 7-percent per year. Even though this choice is basically subjective, it allows the comparison of our capital stocks with those of King and Levine (1994) and Benhabib and Spiegel (1994). Consequently, the steady-state capital-output ratio for country *j* is derived as follows:

$$\kappa_j^* = i_j^* / (\delta + \gamma_j^*), \tag{1}$$

where κ_j^* is the steady-state capital-output ratio, and i_j^* is the steady-state investment rate for country *j*. The steady-state investment rate is the average investment rate for the entire period. The steady-state growth rate is the weighted average of the country's growth rate and the world growth rate. Specifically, the steady-state growth rate of country *j* is

$$\gamma_j^* = \lambda \gamma_j + (1 - \lambda) \gamma_w. \tag{2}$$

where $\lambda = 0.25$ is a measure of mean reversion in the growth rates (Easterly et al.,1993), γ_j is the country growth rate over the entire period, and $\gamma_w = 0.04$ is the world growth rate over the 30 year period.

The calculation of the steady-state capital-output ratio assumes that the capital-output ratio is fixed. We use the steady-state capital-output ratio to calculate each country's initial capital stock. As the steady-state capital-output ratio applies to the initial year, the following holds:

$$K_{j,60} = \kappa_j Y_{j,60} \tag{3}$$

where $Y_{j,60}$, and $K_{j,60}$ are country *j*'s initial GDP and initial capital stock, respectively. The initial capital stock is determined for every country. The calculation of the capital stock for the remaining years uses the perpetual inventory method first developed by Harberger (1978) as follows:

$$K_{j,t+1} = I_{j,t} + (1-\delta)K_{j,t}, \tag{4}$$

where $K_{j,t}$ is the capital stock and $I_{j,t}$ is gross investment for country j at time t. After substitutions, equation (4) generates a function of the initial capital stock and investment flows as follows:

$$K_{j,t} = \sum_{i=0}^{t-1}(1-\delta)^i I_{j,t-i} + (1-\delta)^t K_{j,0} \tag{5}$$

Equation (5) produces a time-series capital stock for all countries and for every year from 1960 to 1989. The sample of countries depends on the availability of the Penn World Tables data on real GDP per capita, investment as a share of GDP, population, and real GDP per worker. Investment comes from real GDP per capita, population, and the investment as a share of GDP, while total real GDP emerges from real GDP per capita and total population. Finally, labor emanates from real GDP and real GDP per worker. The PWT (5.6) gives total population in thousands and real GDP per capita in 1985 international prices. Therefore, the derived capital stock emerges from equation (5) in thousands of 1985 international prices.

Table 1 reports the average output, capital, and labor for each decade and each region, as well as the minimum and maximum averages for countries over the 1980s for the following regions: Africa (23 countries), Latin America (18 countries), West (23 countries), East Asia (9 countries), South Asia (7 countries). Table 1 shows that all three variables increase continuously across the three decades and in all regions. The West possesses the highest averages of real output and physical capital in all three decades, while Africa owns the lowest averages. The labor force, however, emerges as the highest in East Asia and the lowest in Africa.

Table 2 reports the average capital-output and capital-labor ratios, for each decade and each region, as well as the minimum and maximum averages for countries over the 1980's. Table 2 shows that the capital-output ratio increases across the three decades only for Africa, Latin America, and the West. For East and South Asia, the capital-output ratio falls from the 1960s to the 1970s, and then rises into the 1980s. The capital-labor ratio rises across the decades for all regions. The West possesses the highest capital-output and capital-labor ratios, while Africa owns the lowest.

The literature contains only a limited number of studies that estimate panel-data series of capital stocks (Benhabib and Spiegel, 1994, 1997; King and Levine, 1994; and Nehru and Dahreshwar, 1993).[4] To test the accuracy of the calculated capital stocks, we compare our estimated capital stocks with Benhabib and Spiegel, King and Levine, and the Penn World Tables series. In order to make the comparison possible, the countries used and the groupings of the countries were made to be coherent with those two studies.

Benhabib and Spiegel (1994) use the PWT (5) to calculate the initial capital stock. They use the 29-country sample for which PWT (5) provides capital stock data for 1980 and 1985 to estimate a production function between real output, physical capital, labor, and human capital. The estimated coefficients are then used to estimate the initial capital stocks for the remaining countries in the Summers and Heston data set. Capital stocks for subsequent years are calculated from the investment rates.[5] The authors compute the capital stocks using different depreciation rates, 4, 7, and 10 percent. They report actual data for the capital stocks obtained with a 7-

---

[4] Nehru and Dhareshwar (1995) present an excellent review of the different methods to estimate the capital stock.

[5] This procedure introduces a downward bias in the level of the capital stock. That is, the reported capital stock series in PWT reflect the private sector while the investment series include both the private and public sectors.

percent depreciation rate in 1965 and 1985.

Table 3 provides the ratio of our capital stock to the capital stocks reported in the PWT (5), PWT (5.6), and Benhabib and Spiegel (BS). For the purpose of comparison, we only list the capital stocks for the 30 countries in common in the three data sets and for one year, 1985. Table 3 shows that our estimated capital stocks more closely match to those estimated in Benhabib and Spiegel than the PWT (5) and PWT (5.6). In fact, the ratio between our capital stocks and Benhabib and Spiegel's for the 30 countries varies between 0.76 in the Philippines and 1.88 in Argentina, with an average of 1.08.

We also compute correlation coefficients between the four capital stock series. Our estimated capital stock series possesses the highest correlation (0.99) with Benhabib and Spiegel estimates, next highest (0.97) with PWT (5.6), and the lowest (0.71) with the PWT (5). A similar pattern emerges for the correlation of the Benhabib and Spiegel's estimates and the PWT (5.6) and PWT (5) estimates (0.97 and 0.72). Finally, PWT (5.6) and PWT (5) possess a correlation of 0.73. Those results suggest that differences exist in the definitions of capital stocks calculated by Summers and Heston and those calculated by Benhabib and Spiegel and us.[6]

Gapinski (1999) develops a vintage capital model assuming a constant return to scale Cobb-Douglas production function. We adopt a slight modification of Gapinski's method, where

---

[6] We also compare our capital stocks with Benhabib and Spiegel's for 1965 and 1985, and for the countries that are in common in the two series. We estimate those relationships for the 99 countries in common with Benhabib and Spiegel, giving the following:

$$K_{65} = 11{,}000{,}000 + 0.813K_{(BS)65},$$

and

$$K_{85} = 34{,}500{,}000 + 0.864K_{(BS)85},$$

with adjusted R-squares of 0.98 and 0.96, respectively. Even though these results show a strong correlation between the two series for 1965 and 1985, a simple t-test rejects the hypothesis that 0.813 and 0.864 equal one. The coefficient of $K_{(BS)}$ is closer to 1 in the second equation, because the effect of the initial capital stock diminishes over time.

we exclude consideration of the rate of embodiement, to estimate the average age of capital using a discrete-time model as follows:

$$A_t = H_t / K_t = [\sum_{i=1}^{t}(t-i+1)I_i(1-\delta)^{t-i+1} + \overline{A}(1-\delta)^t K_0] / K_t, \qquad (6)$$

where A is the age of the capital stock, $\overline{A}$ is the average age of the initial capital stock, and H is the aggregate age of the capital stock weighted by investment.[7] Consequently, the average age of capital depends only upon the investment growth rate and the depreciation rate. We calculate the average age of capital for the countries for which we estimate the capital stock and provide information for each of the 5 groups that constitute the final analysis.

Table 4 reports the average age of capital for each decade and for the 30-year period for each group. Over the thirty-year period, Africa exhibits the highest age of capital (13.4 years) and East Asia the lowest (7.7 years). The average age of capital in the West, Latin America, and South Asia match each other closely at 8.6, 8.5, and 8.5 years, respectively. On a decade-by-decade basis, the average age of capital is the highest in the first decade in all groups except for Africa, where it is the highest in the second decade. East Asia experiences the fastest decline in the average age of its capital stock. This outcome is expected since East Asian countries have largely focused on industrialization and modernization of their economies since the 1960's. The policy shift of Hong Kong and Singapore from import substitution to export promotion strategies and their high investment rates during the 1960's helps explain the fact that they exhibit the lowest average age of capital. The average age of the U.S capital stock is 8.7 years over the period. This number compares to Gapinski (1996) where the average age for the U.S is 8.8 years, and the U.S Department of Commerce (1993) estimate of the average age of 8.1 years.

Similarly, Table 5 provides information on the mean years of education by decade and by region. The table shows that the West has the highest mean years of education over the 30-year period followed by East Asia, Latin America, South Asia, and Africa.

IV. The Model

Aigner, Lovell, and Schmidt (1977) and Meeusen and Van den Broeck (1977) first introduce the stochastic frontier model, where a stochastic frontier bounds actual production from above. The basic model includes a composite error term that sums a two-sided error term measuring all effects outside the control of the firm and a one-sided non-negative error term measuring technical inefficiency. A firm can lie on or within the frontier, and the distance between actual output and the frontier output represents technical inefficiency. The early articles on stochastic frontiers used cross-section data. With panel data, however, later models (Cornwell, Schmidt, and Sickles, 1990; Kumbhakar, 1990; Battese and Coelli, 1992) include time-varying inefficiency.

This section uses a stochastic frontier analysis to analyze output growth in 80 countries. The technique assumes that given inputs, a maximum attainable output exists. The country's production lies on the frontier, if it uses the inputs efficiently, or within the frontier, if it uses the inputs inefficiently. The distance between the frontier and the actual production point measures technical inefficiency. Over time, a country's performance relative to the frontier includes two factors. First, a country can become more efficient, and get closer to the frontier. Second, the frontier itself can shift over time. Frontier shifts reflect purely technological factors. In addition, a country can move along the frontier by changing inputs. Hence, output growth can be thought

---

[7] The initial average age assumes a steady state situation in 1960. Thus, the 7-percent depreciation rate implies an average age of 14.28 years.

of in terms of three components; efficiency change, technological change, and input change.[8]

To account for differences in the quality of capital and labor between countries, we assume that the productivity of capital and labor directly depends on other qualitative variables. Consequently, we construct a stochastic frontier production function where the productivity of capital and labor depends on the average age of physical capital and the level of human capital, respectively. The older the physical capital, the less new technology embedded in the capital stocks, and the less productive the capital. Similarly, the level of education increases the productivity of labor. That is, the more educated the labor force is, the higher the labor productivity.

We assume a standard Cobb-Douglas production function, where aggregate output is produced using the aggregate physical capital stock and labor:

$$Y_{it} = A_t K_{it}{}^{\beta_{1it}} L_{it}{}^{\beta_{2it}}, \qquad (7)$$

where Y_{it}, K_{it}, and L_{it} represent country i's real GDP, physical capital stock, and labor at time t, and A_t equals $Ae^{\xi t}$, where ξ measures the rate of technical progress. The parameters β_{1it} and β_{2it} measure the elasticities of output with respect to capital and labor, respectively. To allow differences in the quality of inputs between countries, we assume that the productivity of capital and labor directly depends on the average age of capital and the level of human capital, respectively. Consequently, we assume that the coefficients β_{1it} and β_{2it} are linear functions of age and education, respectively. Thus,

---

[8] A simple growth accounting analysis that only looks at input quantity and an exogenous technology does not take into account the country's efficiency in using its inputs and the available technology. This is especially true for developing countries where serious institutional obstacles can impede the production process and cause a misuse not only of capital and labor, but also of the imported technology. A stochastic frontier analysis evaluates these effects as technical inefficiency. By separating technical inefficiency from other variables, a stochastic frontier analysis decomposes TFP into factors that are external to the country (technological change) and factors that are internal to the country (its ability to absorb and use the available inputs).

$$\beta_{1it} = \alpha_1 + \alpha_2 V_{it} \quad (8)$$

and

$$\beta_{2it} = \delta_1 + \delta_2 H_{it}, \quad (9)$$

where V_{it} represents country *i*'s average age of physical capital (or vintage) at time *t*, and H_{it} represents country *i*'s mean years of secondary education (or human capital) at time *t*. Because older capital incorporates less new technology, one expects that the higher the average age, the less productive the capital stock. Similarly, the more educated workers are, the higher the productivity of labor. Consequently, the sign of α_2 is negative, and the sign of δ_2 is positive. After substituting equations (8) and (9) into equation (7) and after taking natural logarithms, equation (7) becomes after adding the one- and two-sided error terms:

$$ln\,Y_{it} = ln\,A + \alpha_1\, ln\,K_{it} + \alpha_2 V_{it}\, ln\,K_{it} + \delta_1\, ln\,L_{it} + \delta_2 H_{it}\, ln\,L_{it} + \xi t + v_{it} - u_{it} \quad (10)$$

where v_{it} equals the standard two-sided random error and u_{it} represents technical inefficiency (Battese and Coelli, 1992). Further,

$$u_{it} = \eta_{it} u_i = exp[-\eta(t-T)]u_i \qquad (t = 1, \ldots T;\ i = 1, 2, \ldots, N) \quad (11)$$

where η captures the rate of decline in technical inefficiency. Finally, the technical efficiency measures for every country and every year are calculated as follows:

$$\hat{TE}_{it} = exp(-u_{it}). \quad (12)$$

We estimate equations (10) and (11) for a sample of 80 countries and over the period 1960-89.[9] We first estimate a single world frontier for all countries. The construction of a world frontier assumes that countries share or have access to the same technology. Then grouping countries into five subgroups, largely by geographical location, the following subgroups are

---

[9] We use the "FRONTIER" program developed by Coelli (1996).

represented: Africa (23 countries), Latin America (18 countries), East Asia (9 countries), South Asia (7 countries) and the West (23 countries). The appendix gives a complete list of the countries used in this study.

Most data come from the Penn World Tables 5.6 (PWT5.6) and our own calculations. Total output equals real GDP per capita times total population. We use the total number of workers to approximate total labor. The total number of workers equals total GDP divided by GDP per worker. The data on capital stocks is derived in Section III. To approximate the level of human capital, we use the mean years of secondary education as calculated in Nehru and Dhareshwar (1993). The data set, however, only provides information from 1960 to 1987. We use the given data to predict the values for 1988 and 1989. In addition, Nehru and Dhareshwar do not provide data for Taiwan and Hong Kong as these countries do not enter in the World Bank country listing. Therefore, for Taiwan and Hong Kong, We use the means years of secondary education from Barro and Lee (1994).

Before reporting the results, we perform several hypotheses tests to reduce the extent of findings reported. First, we test the assumption that regional frontiers are a better specification than one global frontier. Second, for each region, we test whether a stochastic frontier specification is better than an OLS model. Third, and for each group, we test for the statistical distribution of the one-sided error term; half-normal or a truncated-normal. Finally, for each group, we test whether technical efficiency is time varying or time invariant. We find that regional frontiers exhibit different technologies and dominate aggregation into a world frontier; the stochastic frontier dominates the ordinary least squares model; the half normal distribution dominates the truncated normal; and technical efficiency varies over time.

The neoclassical model often receives criticism because it does not explain international differences in output growth. In an influential paper, Mankiw (1995) argues that the magnitude of the capital share is the key reason behind problems of the neoclassical model. By broadening capital stock to include human capital, Mankiw finds a coefficient on capital that better fits the model. Based on these results, we expect that the inclusion of human capital and the average age of physical capital affect the respective elasticities of capital and labor. To calculate the output elasticity of capital, we differentiate equation (10) with respect to the natural logarithm of capital to derive the output elasticity of capital as follows:

$$\frac{\partial \ln Y_{it}}{\partial \ln K_{it}} = \alpha_1 + \alpha_2 V_{it} . \tag{13}$$

Similarly, the output elasticity of labor is:

$$\frac{\partial \ln Y_{it}}{\partial \ln L_{it}} = \delta_1 + \delta_2 H_{it} . \tag{14}$$

With different values of V and H over countries and over time, equations (13) and (14) do not allow the calculation of a single value for capital and labor elasticity for each group. Consequently, we calculate a range of output elasticities using the minimum and the maximum values of V and H in each group.

The results from estimating equation (10) show that the coefficients on capital and labor are positive and significant in all groups (See Table 6). The coefficients on the average age of capital interaction term are strongly negative in all groups. The coefficients, however, do not produce sizeable effects, as we shall see latter. The coefficients on the human capital interaction term are positive and significant in Africa, East Asia, and West, but negative and significant in Latin America, and South Asia. Once again, those coefficients do not produce sizable effects. Technical efficiency significantly improves in Africa, Latin America, and the West, but significantly falls in East Asia and South Asia. Finally, the coefficients on the time trend are positive and significant in East Asia and South Asia, but negative an significant in Africa, Latin America, and the West.

The estimated coefficient for γ for Africa, East Asia, Latin America, South Asia, and West are, respectively, 0.99, 0.98, 0.91, 0.99, and 0.93. These results indicate that technical efficiency explains most of the error variations in the five groups, with the smallest share in Latin America and the West.

Table 7 reports the results for the technical efficiency estimates – means, statndard deveiations, and minimum and maximum values. The two regions with the lowest average efficiency – Africa and South Asia – also exhibit the highest variability of efficiencies. The West possesses the highest average efficiency (85.5%) and the lowest variability (8.5). East Asia and then Latin America exhibit the second (79.9%) and third (77.7%) highest average efficiencies and second (11.4) and third (14.9) lowest variabilities.

We next decompose output growth into input growth, input quality change, efficiency change, and technological change. The role of physical capital in economic growth is a controversial topic and is often linked to the level of development. The stochastic frontier framework that we adopt allows a better look at the components of output growth because it accounts for changes in efficiency. In addition, the model permits the distinction between the quantity and the quality of the inputs. The growth of output equals the total derivative of equation (1) with respect to time. Consequently, equation (10) in growth rates becomes:

$$\frac{\dot{Y}}{Y} = (\alpha_1 + \alpha_2 V)\frac{\dot{K}}{K} + \alpha_2 V \ln K \frac{\dot{V}}{V} + (\delta_1 + \delta_2 H)\frac{\dot{L}}{L} + \delta_2 H \ln L \frac{\dot{H}}{H} + \frac{\dot{TE}}{TE} + \xi , \qquad (15)$$

where dots over variables represent time derivatives. The time derivative of variable *X* is approximated by the difference between the natural logarithm of *X* between the year *t* and *t-1*.

That is,

$$\frac{\dot{X}}{X} = \ln X_{it} - \ln X_{it-1}\text{; where } X=Y, K, L, V, H, \text{ and } TE.$$

Equation (15) illustrates that the percentage change in output includes: 1) The change in the effective units of capital; 2) the change in the average age of capital; 3) the change in the effective units of labor; 4) the change in the mean years of education; 5) the efficiency change, and 6) the technological change (the residual).

The second and fourth terms on the right hand side of equation (15) capture the part of output growth explained by changes in the quality of inputs. The model permits output to change even if no change in the quantity of capital and labor occurs. For example, higher output growth can occur without higher labor growth, if the human capital embodied in labor increases. Similarly, higher output growth can occur without higher capital growth, if the capital gets younger. We calculate the different components of output growth for the five regional groups.

Table 8 reports the results of the output growth decomposition by decade, over the entire sample, and by country groups. The results indicate that physical capital, labor, and technological change all contribute importantly to output growth. Their strengths, however, vary across groups. The cpontribution to output growth of physical capital is the largest in Africa and the West where it accounts for 78.5 and 79.7 percent of total output growth, and the lowest in South Asia where physical capital explains only 3.4 percent of output growth. Meanwhile, the cpontribution to output growth of labor is the highest in Africa where it accounts for 40.8 percent of total output growth, and the lowest in South Asia where it explains -5.3 percent of total output growth.

In all groups, the findings show that physical capital's cpontribution to output growth far exceeds labor's contribution. According to Gapinski (1999) "…labor quantity appears to be a weak foundation on which to build strong growth" (p. 125). Technological change possesses the highest share in total output growth in South Asia at 84.7 percent followed by East Asia at 30.6 percent, and the lowest in Africa at –44.6 percent.

Narrowing our focus within the output growth determinants to include the change in input quality reveals that quantity dominates quality by a wide margin for both capital and labor. To illustrate, in East Asia, the total output growth is 6.89 percent over the period. This rate includes an increase in physical capital of 3.55 percent, which constitutes 51.5 percent of total output growth, and the quality of capital contributes only 0.58 percent to output growth, or only 4.8 percent of total output growth. Moreover, in East Asia, labor explains 14.4 percent of total output growth, while the quality of labor explains only 3.3 percent.

To better isolate the input effect from the quality effect, we calculate the total input and the total quality share in output growth for each group. By summing the capital and labor share in output growth, total inputs explain 119.3 percent of output growth in Africa while they explain 65.9, 101.4, 38.1, and 87.5 percent of total output growth in East Asia, Latin America, South Asia, and the West. By summing the contributions of the quality of capital and labor, the results show that qualitative variables contribute 1.9, 8.1, 2.3, -11.2, and 3.4 percent of total output growth in the five regions, respectively.

Table 8 shows that the quality of capital has a positive effect on output growth in East Asia, South Asia, Latin America, and West. South Asia has the highest contribution of the quality of capital to total output growth (5.5 percent) followed by Latin America (5.3 percent), East Asia (4.8 percent), and the West (2.1 percent). Those results imply that East Asia, the West, South Asia, and Latin America acquired new capital more quickly than the existing capital aged during the period. In Africa, the quality of capital contributes negatively to output growth (–1.9 percent).

Shifting to labor quality, Table 8 shows that labor quality exerts the highest effect on output growth in Africa (3.8 percent) and East Asia (3.3 percent), followed by the West (1.3 percent). In Latin America and South Asia, the cpontribution to output growth of human capital is negative. The negative contribution of labor to output growth in Latin America and South Asia relates to the returns of education in developing countries. In some developing countries, large efforts to increase education with no corresponding increase in output leads to erroneous results about human capital.

In sum, output growth decomposition shows that physical capital, or factor, accumulation provides the most important component of output growth in nearly all groups, except in South Asia where technical change possesses the largest effect. Technological change generates the second largest component of output growth in East Asia while in the Africa, Latin America, and the West, labor growth is second most important. In all groups, the quality of capital and labor explain small components of output growth.

These results correlate well with Gapinski (1999), who determines the contribution of different output components to economic growth. After distinguishing between quantity and quality, Gapinski (1999) finds that with the exception of the Latin Rim group, all country groups rank international trade, capital quantity, and labor quantity as the top three determinants of output growth while capital quality and labor quality are the bottom two forces.

Whether factor accumulation or TFP growth contributes more to output growth remains perhaps the most controversial question in the mainstream growth theory. Solow (1956) argues that the residual and not factor accumulation accounts for the bulk of output growth in the US.

Easterly and Levine (2001) and King and Levine (1994) also find that the residual accounts for most of the income and output growth differences across countries. On the other hand, Kim and Lau (1996) and Koop et. al (1999) argue in favor of factor accumulation. To evaluate the role of TFP in output growth, we also calculate the share of TFP growth in total output growth for each group.

Jorgensen and Griliches (1967) calculate the rate of growth of TFP as the difference between the rate of change of real product and the rate of growth of inputs. Applying this definition to equation (10), the change in TFP can be calculated as follows:

$$\frac{T\dot{F}P}{TFP}=\frac{\dot{Y}}{Y}-\left[(\alpha_1+\alpha_2 V)\frac{\dot{K}}{K}+(\delta_1+\delta_2 H)\frac{\dot{L}}{L}\right].$$

The last column of Table 8 shows the growth in *TFP* and its contribution to output growth. Results show that in all groups input growth exceeds by far *TFP* growth. The share of *TFP* growth is the highest in East Asia and South Asia where *TFP* growth contributes, relatively to 34.1 and 61.9 percent of total output growth. In the West, *TFP* growth explains 12.5 percent of total output growth, while in Latin America (-1.4 percent) and Africa (-19.3), the contributions of *TFP* to total output growth are negative.

The result that factor accumulation accounts for a large share of output growth is shared by most frontier studies. Koop et. al (1999) estimate country technical efficiency for the OECD countries, and decompose output growth into input, efficiency, and technological change components. On a general level, they find that factor accumulation explains most of the output growth. In their analysis, technological change comes second, while the share of efficiency growth is minimal.

Koop et al (2000) also use a stochastic frontier analysis with factor correction and use country grouping to do their analysis. They use levels of education to correct for labor, and the percentage of the labor force in agriculture and in industry to correct for physical capital. Similar to our results, Koop et al find that factor accumulation and not TFP accounts for most of the change in output in all groups. In addition, they find that technological change plays the most important role in East Asia, where it accounts for about half of output growth, while Africa and the West experience much less technological progress.

Many growth accounting and cross-country studies do not share the view that physical capital (factor) accumulation is the main source of output growth, though. In their classic papers, Solow (1956) and Denison (1962) conducted growth accounting exercises on a number of developed countries to determine the effect of capital accumulation on output growth. They find that the rate of capital accumulation per capita accounts for between 1/8 and 1/4 of total output growth in the U.S, while TFP accounts for more than half of output growth in most countries. Easterly and Levine (2001) conduct a similar analysis using the Penn World Tables capital stock data. They find that on average, TFP accounts for about 60 percent of output per worker growth. In addition, they find that the share of capital growth accounts for less than the share of output growth.

Elias (1990) also conducts a growth accounting study for several Latin America countries. He finds a larger variation in the share of TFP growth, the average hovers around 30 percent. Perhaps the most mixed results come from East Asia. Most studies seem to agree on the unprecedented growth in total factor productivity experienced by the East Asian countries during the 1970's and 1980's (Christensen and Cummings, 1981, Dollar and Sokoloff, 1990; Kim and Lau, 1996). Young (1994), however, criticizes those studies, and argues that the productivity growth in the East Asian countries is largely overestimated. Young argues that factor accumulation played a fundamental role in the extraordinary postwar output growth of the East Asian countries. Several factors lead to this conclusion, mainly increased participation rates of the labor force and a skyrocketing investment rate especially in machinery.

King and Levine (1994) conduct a growth accounting analysis for the 100 countries for which they calculate the capital stock. Their findings are that growth in capital per person accounts for only 40 percent of the growth of output per person. The authors conclude that expanding Denison's data to 100 countries does not change the results of growth accounting, capital accumulation accounts for only a small share of output per capita growth.

V. Conclusion

This paper analyzes output and productivity growth for a pooled cross-section, time-series sample of developed and developing countries. It contributes to the existing growth literature in three major aspects. First, we estimate the capital stock series and the average age of capital for a sample developed and developing countries and for a period of thirty years. Second, we use the stochastic frontier methodology to calculate each country's technical efficiency, and examine the potential sources of output and productivity growth. Finally, we present a model of output growth where the productivity of capital and labor changes according to qualitative variables.

The lack of information on capital stocks especially for developing countries limits most studies of growth to developed countries. We estimate the capital stocks for 104 countries from 1960 to 1989, following a slight modification of King and Levine (1994).. Following King and Levine, we use the steady state capital-output value to calculate the initial capital stock for each country. Then, we apply the perpetual inventory method to calculate the capital stock for subsequent years. We compare our capital stocks to those in the Penn World Tables (5) and (5.6), Benhabib and Spiegel (1994), and King and Levine (1994). The correlation coefficient between our capital stocks and those in Benhabib and Spiegel, the PWT (5), and the PWT (5.6) in 1985 generates a correlation of 0.99, 0.71, and 0.97, respectively.

We employ stochastic frontier analysis (Battese and Coelli, 1992), grouping countries into five regions and testing the hypothesis of a single world frontier versus regional group frontiers. The following regions are represented: Africa, East Asia, Latin America, South Asia, and the West. We reject the null-hypothesis that production technology represents a global frontier in favor of the alternative hypothesis that country groups exhibit different technologies. Consequently, we estimate a frontier for each region and calculate each country's distance from the frontier as technical inefficiency.

We use a Cobb-Douglas specification that includes the capital stock and the labor force, as well as the average age of physical capital and the mean years of education to account for the quality of capital and labor, respectively. The coefficients on capital and labor prove significant in all models and for all groups. Moreover, the average age of physical capital possesses a negative and significant effect in all models and for all groups. The negative effect of the average age of capital indicates that older capital exhibits lower productivity. Human capital possesses a positive and significant effect on output in Africa, East Asia, and the West, but a negative and significant effect on output in Latin America and South Asia. The mixed findings for human capital probably reflect the tremendous spending of some developing countries on education programs that by in large, do not produce higher economic activity or higher output.

The decomposition of output growth demonstrates that factor growth generally proves much more important than either the improved quality of factors or total factor productivity growth in explaining output growth. The exception, South Asia, shows that total factor productivity growth explains a larger share of output growth than factor accumulation.

A negative correlation exists between technical efficiency improvement and technical change. For example, the low growth country groups of Africa and Latin America explain over 100 percent of their average output growth rate with factor accumulation. Technical regress accounts for the largest negative factor in economic growth. But in both country groups, technical efficiency improvement contributes positively to economic growth, reducing but not eliminating the negative effect of technical regress on total factor productivity. On the other hand, the high-growth country groups of East and South Asia each exhibit significant technical progress, helping to explain output growth. At the same time, these two country groups also experience technical efficiency regress, suggesting that technical efficiency trades-off grossly with rapid economic growth.[10] In sum, fast economic growth associates with declining technical efficiency, and vice versa.

---

[10] In fact, the worsening of technical efficiency is the only negative contributor to output growth in East Asia. That is, the East Asian growth miracle does depend on factor accumulation and total factor productivity growth. And total factor productivity growth significantly responds to technical progress. The only cost is a worsening technical efficiency.

Finally, important policy implications emerge from the analysis. Since factor accumulation proves the most important component of output growth, economic policies designed to increase factor supplies can spur economic growth. Labor's cpontribution to output growth is the most important in Africa. The slow economic growth of the African countries suggests that economic policies based on labor do not lead to successful output growth.[11] The mixed results on education, especially in developing countries, suggest that increasing education is not enough, and that educational policies must be followed by the right economic and social policies. More precisely, developing countries must reduce inefficient government enterprise and unproductive bureaucracies that represent a major obstacle to their development.

---

[11] Growth of the labor force, however, associates with lower labor productivity and a lower standard of living, assuming that the labor force participation rate does not change drastically.

REFERENCES

Aigner, Dennis, C.A.Knox Lovell, and Peter Schmidt (1977), "Formulation and Estimation of Stochastic Frontier Production Function Models." *Journal of Econometrics* 6: 21-37.

Barro, Robert J. (1991), "Economic Growth in a Cross Section of Countries." *Quarterly Journal of Economics* 106: 407-443

Barro, Robert J., and Jong Wha Lee (1994) "International Comparisons of Educational Attainment." *Journal of Monetary Economics* 32: 363-394.

Barro, Robert, and Xavier Sala-i-Martin (1992) "Convergence" *Journal of Political Economy* 100 (April): 223-251.

Barro, Robert, and Xavier Sala-i-Martin (1995), "Technological Diffusion, Convergence and Growth." *NBER Working Paper Series,* Working Paper No.5151.

Basu, Susanto, and David N. Veil (1998), "Appropriate Technology and Growth." *Quarterly Journal of Economics* 113 (November): 1025-1054.

Battese, G.E, and T.J. Coelli (1992), "Frontier Production Functions, Technical Efficiency, and Panel Data: With Applications to Paddy Farmers in India." *The Journal of Productivity Analysis* 3: 153-169.

Benhabib, Jess, and Mark M. Spiegel (1994), "The Role of Human Capital in economic Development: Evidence from Aggregate Cross-Country Data." *Journal of Monetary Economics* 34: 363-390.

Benhabib, Jess, and Mark M. Spiegel (1997), "Cross-Country Growth Regressions." Economic Research Reports, New York University, New York, NY.

Christensen, Laurits R., and Dianne Cummings (1981), "Real Product, Real Factor Input, and Productivity in the Republic of Korea 1960-1973." *Journal of Development Economics* 8:285-302.

Christiansen, L.R.D. Cummings, and D. Jorgenson (1980), " Economic Growth, 1947-1973: An International Comparison." In J.W. Kendrick and B. Vaccara (eds.), *New Developments in Productivity Measurement and Analysis*. Studies in Income and Wealth 41, Chicago: University of Chicago Press.

Coelli, T.J. (1996), "A Guide to FRONTIER Version 4.1: A Computer Program for Stochastic Frontier Production and Cost Function Estimation." CEPA Working Paper 97/07, Center for Efficiency and Productivity Analysis, University of New England, Armidale.

Cornwell, C., P. Schmidt, and R.C. Sickles (1990), " Production Frontier with Cross-Sectional and Times-Series Variation in Efficiency Levels." *Journal of Econo*metrics 46: 185-200.

Denison, Edward, F. (1962), "Sources of Economic Growth in the United States and the Alternative Before Us." New York: Committee for Economic Development.

Dollar, David, and Kenneth Sokoloff (1990), "Patterns of Productivity Growth in South Korean Manufacturing Industries, 1963-1979." *Journal of Development Eco*nomics 33:309-327.

Domar, E. (1946), "Capital Expansion, Rate of Growth and Employment" *Econometrica* 14: 137-47.

Easterly, William, and Ross Levine (2001), "It's Not Factor Accumulation: Stylized Facts and Growth Models." *The World Bank Economic Review* 15(2): 177-219.

Easterly, W., Kremer, M., Pritchett, L., and Summers L., (1993), "Good Policy or Good Luck? Country Growth Performance and Temporary Shocks." *Journal of Monetary Economics* 32: 459-84.

Eaton, Jonathan, and Samuel Kortum (1995), "Engines of Growth Domestic and Foreign Sources of Innovation." *NBER Working Paper Series,* Working Paper No.5207.

Eaton, Jonathan, and Samuel Kortum (1996), "Measuring Technology Diffusion and The International Sources of Growth." *Eastern Economic Journal* 22 (4): 401-410.

Elias, Victor, J. (1990), Sources of Growth. A Study of Seven Latin American Economies. International Center for Economic Growth.

Fare, Rolf, Shawna Grosskopf, Mary Norris, and Zhongyang Zhang (1994), "Productivity Growth, Technical Progress, and Efficiency Change in Industrialized Countries." *The American Economic Review* 84: 66-83.

Feenstra, Robert, C. (1996), "Trade and Uneven Growth*." Journal of Development Economics* 49(1), April: 229-56.

Gapinski, James, H. (1996a),"Economic Growth and Its Components in African Nations." *The Journal of Developing Areas* 30: 525-548.

Gapinski, James, H. (1996b), "Heterogeneous Capital, Economic Growth, and Economic Development." *Journal of Macroeconomics* 18 (4): 561-585.

Gapinski, James, H. (1999), *Economic Growth in the Asia Pacific Region*, St. Martin Press, New York, NY.

Grossman, Gene M., and Elhanan Helpman (1991), *Innovation and Growth in the Global Economy*, Cambridge: MIT Press.

Harberger, A. (1978), "Perspectives on Capital and Technology in Less Developed Countries" in M.J. Artis and A.R. Nobay (eds.), *Contemporary Economic Analysis* (London: Croom Helm).

Harrod, R.F. (1939), "An Essay in Dynamic Theory" *Economic Journal* 49: 14-33.

Henderson, Daniel J., and Robert R. Russell (2001), "Human Capital and Macroeconomic Convergence: A Production Frontier Approach." Paper Presented at the 7th European Workshop on efficiency and Productivity Analysis. Oviedo, Spain.

Jorgenson, D.W., and Z. Griliches (1967), "The Explanation of Productivity Change." *Review of Economic Studies* 34 (July): 249-280.

Keller, Wolfgang (1996), "Absorptive Capacity: On the Creation and Acquisition of Technology in Development." *Journal of Development Economics*, Special Issue (April): 448-454.

Kim, Jong-il, and Lawrence J. Lau (1996), " The Sources of Asian Pacific Economic Growth." *Canadian Journal of Economics*, Special Issue (April): 448-454.

King, Robert J., and Ross Levine (1994), "Capital Fundamentalism Economic Development and Economic Growth." *Carnegie-Rochester Conference Series on Public Policy* 40 (June): 259-292.

Koop, Gary, Jacek Osiewalski, and Mark F.J. Steel (1999), "The Components of Output Growth: a Cross-Country Analysis." *Oxford Bulletin of Economics and Statistics* 61: 455-487.

Koop, Gary, Jacek Osiewalski, and Mark F.J. Steel (2000), "Modeling the Sources of Growth in a Panel of Countries." *Journal of Business and Economic Statistics* 18(3): 284-299.

Kumbhakar, S.C. (1990), "Production Frontiers, Panel data, and Time Varying Technical Inefficiency." *Journal of Econometrics* 27: 201-11.

Lewis, W.A. (1954), "Economic Development With Unlimited Supplies of Labor." *The Manchester School of Economics and Social Studies* 22 (2): 139-91.

Lucas, Robert E. (1988), "On the Mechanics of Economic Development" *Journal of Monetary Economics* 22: 3-42.

Mankiw, Gregory (1995), "The Growth of Nations." *Brooking Papers on Economic Activity*. Washington, DC: Brooking Institution (1): 275-310.

Mankiw, Gregory N., David Romer, and David N. Weil (1992), "A Contribution to the Empirics of Economics Growth." *The Quarterly Journal of Economics* (May): 407-437.

Miller, Stephen M., and Mukti P. Upadhyay (2000), "The effects of Openness, Trade Orientation and Human Capital on Total Factor Productivity." *Journal of Development Economics* 63(2) December: 399-423.

Meeusen, W., and J. van den Broeck (1977), "Efficiency Estimation from Cobb-Douglas Production Functions with Composed Errors." *International Economic Review* 18: 435-444

Nehru, V. and A. Dhareshwar (1993), " A New Database on Physical Capital Stocks: Sources Methodology and Results." *Revista de Analisis Economico* 8 (June): 37-59

Parente, Stephen L., and Edward C. Prescott (1994), "Barriers to Technology Adoption and Development." *Journal of Political Economy* 102 (April): 298-321.

Pissarides, Christopher A. (1997), "Learning by Trading and The Returns to Human Capital in Developing Countries." *The World Bank Economic Review* 11(1): 19-32

Rivera-Batiz, Luis A., and Paul Romer (1991a), "International Trade with Endogenous Technological Change." *European Economic Review* 35: 971-1004.

Rivera-Batiz, Luis A., and Paul Romer (1991b), "Economic Integration and Endogenous Growth." *Quarterly Journal of Economics* (May): 531-555.

Romer, Paul M. (1986), "Increasing Returns and Long-Run Growth." *Journal of Political Economy* 94 (October): 1002-1036.

Romer, Paul M. (1990), "Endogenous Technological Change." *Journal of Political Economy* 98: 71-102.

Romer, Paul M. (1994), "The Origins of Endogenous Growth." *Journal of Economic Perspectives* 8 (Winter): 2-22.

Solow, Robert (1956), "A Contribution to the Theory of Economic Growth." *Quarterly Journal of Economics* 70 (February): 65-94.

Summers, Robert, and Alan Heston (1991), "The Penn World Table (Mark 5): An Expanded Set of International Comparisons, 1950-1988." *The Quarterly Journal of Econom*ics (May): 327-368. (Version 5.6 released January 1995, and updated to 1992).

Tallman, Ellis W., and Ping Wang (1994), " Human Capital and Endogenous Growth Evidence from Taiwan." *Journal of Monetary Economics* (34): 101-124.

U.S. Department of Commerce. Bureau of Economic Analysis (1993), *Fixed Reproducible Tangible Wealth in the United States, 1925-89.* Washington: U.S. Government Printing Office, January.

Young, Alwyn, (1994), "Lessons from the East Asian NIC's: A Contrarian View." *European Economic Review* 38: 964-973.

APPENDIX:

Africa (23 countries)*:* Algeria, Angola, Cameroon, Egypt, Ghana, Ivory Coast, Kenya, Madagascar, Malawi, Mali, Mauritius, Morocco, Mozambique, Nigeria, Rwanda, Senegal, Sierra Leone, Tanzania, Tunisia, Uganda, Zaire, Zambia, Zimbabwe.

Latin Ame*rica* (18 countries): Argentina, Bolivia, Brazil, Chile, Colombia, Costa, Rica, Ecuador, El Salvador, Guatemala, Haiti, Honduras, Jamaica, Mexico, Panama, Paraguay, Peru, Uruguay, Venezuela.

South Asia (6 countries): Bangladesh, India, Indonesia, Iran, Pakistan, Sri Lanka.

East Asia (9 countries): China, Hong Kong, Japan, Korea, Malaysia, Philippines, Singapore, Taiwan, Thailand.

West (23 countries): Australia, Austria, Belgium, Canada, Denmark, Finland, France, Germany, Greece, Iceland, Ireland, Israel, Italy, Netherlands, New Zealand, Norway, Portugal, Spain, Sweden, Switzerland, Turkey, United Kingdom, United States.

Table1: Average Values of Output, Capital, and Labor for Alternative Regions (80 countries).

Group	60s	70s	80s	60-89	Minimum (Av. 80-89)	Maximum (Av. 80-89)
Real Output (in billions)						
Africa	7.89	13.56	19.25	13.57	1.21 (Botswana)	66.89 (Nigeria)
East Asia	111.30	218.63	362.69	146.28	0.48 (China)	930.49 (Japan)
Latin America	34.69	62.51	86.15	61.12	4.26 (Honduras)	359.09 (Brazil)
South Asia	91.16	138.83	215.20	148.40	14.16 (Myanmar)	551.71 (India)
West	203.43	296.55	375.93	291.97	2.01 (Iceland)	3054.96 (USA)
Physical Capital Stock (in billions)						
Africa	6.62	12.19	21.23	13.34	0.53 (Zaire)	86.08 (Nigeria)
East Asia	226.46	472.34	840.00	363.03	0.60 (China)	2645.48 (Japan)
Latin America	52.82	95.29	151.25	99.79	2.46 (Haiti)	602.15 (Brazil)
South Asia	104.39	157.84	278.02	180.09	11.30 (Myanmar)	719.72 (India)
West	442.91	686.05	906.62	678.53	5.17 (Iceland)	6531.81 (USA)
Labor (in millions)						
Africa	3.90	4.65	5.98	4.84	0.29 (Botswana)	27.52 (Nigeria)
East Asia	53.32	67.89	84.60	68.60	0.87 (Singapore)	485.48 (China)
Latin America	4.14	5.40	7.05	5.53	0.59 (Panama)	37.66 (Brazil)
South Asia	42.85	51.44	63.80	52.70	4.82 (Sri Lanka)	245.45 (India)
West	10.93	12.30	13.98	12.40	0.10 (Iceland)	97.73 (USA)

Table 2: Average Capital-Output and Capital-Labor Ratios by Decade and by Region (80 countries).

Region	60s	70s	80s	60-89	Minimum (Av. 80-89)	Maximum (Av. 80-89)
Capital-Output Ratio						
Africa	0.82	0.84	0.93	0.86	0.18 (Madagascar)	2.33 (Zambia)
East Asia	1.69	1.66	1.97	1.77	1.39 (Thailand)	3.04 (Japan)
Latin America	1.40	1.46	1.69	1.52	0.71 (Haiti)	2.44 (Jamaica)
South Asia	0.94	0.91	1.12	0.99	0.37 (Bangladesh)	2.00 (Iran)
West	2.34	2.46	2.57	2.46	1.95 (U.K)	3.34 (Finland)
Capital-Labor Ratio						
Africa	2330	3196	3918	3148	309 (Madagascar)	27793 (Algeria)
East Asia	7506	13631	23748	14962	3530 (China)	56528 (Japan)
Latin America	11044	14656	16699	14133	1509 (Haiti)	42370 (Venezuela)
South Asia	3566	4671	6535	4924	1032 (Myanmar)	24673 (Iran)
West	37718	53375	63225	51439	14829 (Turkey)	96288 (Switzerland)

Table 3: Capital Stock Ratios with PWT(5), PWT(5.6) and BS for 1985

Country	PWT(5.6)	PWT(5)	BS
Argentina	2.57	3.03	1.88
Australia	2.36	2.73	1.11
Austria	2.17	2.37	1.03
Belgium	2.05	1.61	1.07
Botswana	2.11	3.50	0.83
Canada	2.04	1.76	1.02
Chile	2.80	2.56	1.30
Colombia	1.10	1.58	0.87
Denmark	2.12	2.11	1.08
Dominican Republic	2.17	2.22	0.98
Finland	2.06	1.80	1.13
France	2.42	2.09	1.13
Germany, West	2.23	2.08	1.15
Greece	1.78	2.60	1.08
Guatemala	1.91	2.32	1.05
India	2.02	2.30	1.11
Ireland	2.42	2.09	1.04
Israel	2.18	2.41	0.93
Italy	2.58	2.24	1.05
Japan	2.01	1.58	1.18
Kenya	2.45	2.12	0.95
Korea, Republic of	1.69	1.39	0.96
Norway	1.84	1.72	0.99
Philippines	1.97	2.75	0.76
Spain	2.51	2.19	1.13
Sweden	2.07	2.65	1.19
Thailand	1.70	2.47	1.14
United Kingdom.	2.52	2.07	1.04
United States	2.50	2.43	1.22
Zimbabwe	0.84	2.22	0.89
Average	2.11	2.23	1.08

Table 4: Average Age of Capital by Decade and by Region.

Region	60s	70s	80s	80-89	Minimum	Maximum
Africa	10.82	19.55	9.95	13.44	5.2 (Morocco)	25.16 (Rwanda)
East Asia	10.13	6.76	6.31	7.73	5.14 (Singapore)	14.28
Latin America	10.11	8.3	7.12	8.51	5.32 (Panama)	14.28
South Asia	10.24	7.59	7.56	8.46	5.3 (India)	14.28
West	9.83	8.62	7.22	8.56	5.18 (Israel)	14.28

Table 5: Mean Years of Education by Decade and by Region.

Region	60s	70s	80s	60-89	Minimum	Maximum
Africa	1.51	2.20	3.04	2.25	0.08 (Angola)	6.83 (Mauritius)
East Asia	4.30	5.38	6.79	5.49	1.64 (Hong Kong)	11.19 (Japan)
Latin America	3.80	4.59	5.65	4.68	1.48 (Honduras)	8.29 (Mexico)
South Asia	1.95	2.63	3.44	2.67	0.80 (Iran)	6.47 (Sri Lanka)
West	7.45	7.83	8.41	7.90	1.89 (Turkey)	16.08 (Ireland)

Table 6 Frontier Results, Adjusting for Capital and Labor Efficiency

Variables	Africa	East Asia	Latin America	South Asia	West
Intercept	2.4935*	4.9954*	2.9258*	9.3409*	1.8972*
	(5.34)	(15.93)	(22.74)	(6.88)	(6.51)
Capital	0.6521*	0.5116*	0.6305*	0.5733*	0.7639*
	(28.98)	(16.77)	(40.27)	(10.73)	(32.37)
Labor	0.5827*	0.3688*	0.4847*	-0.0488	0.2165*
	(10.47)	(15.50)	(20.13)	(-0.48)	(8.77)
Age	-0.00017*	-0.0016*	-0.0015*	-0.0014*	-0.0005*
	(-4.74)	(-9.25)	(-11.46)	(-4.44)	(-7.90)
Education	0.0041**	0.0045*	-0.0032*	-0.0206*	0.0028*
	(2.21)	(6.75)	(-3.19)	(-6.53)	(5.44)
T	-0.0144*	0.0211*	-0.0091*	0.0371*	-0.0014**
	(-7.25)	(9.50)	(-8.49)	(8.05)	(-2.24)
LLF	356.38	307.31	604.24	131.95	1129.16
$\sigma^2 = \sigma_v^2 + \sigma_u^2$	1.5814*	0.2128†	0.0561*	1.3190†	0.0269*
	(3.18)	(2.10)	(3.33)	(1.43)	(3.05)
$\gamma = \sigma_u^2/\sigma^2$	0.9895*	0.9760*	0.9063*	0.9898*	0.9313*
	(284.16)	(83.68)	(30.59)	(132.46)	(40.95)
η	0.0053*	-0.0428*	0.0247*	-0.0071*	0.0123*
	(3.83)	(-7.85)	(12.33)	(-3.38)	(5.44)

* means significant at the 1% level.
** means significant at the 5% level
† means significant at the 10% level
LLF = Log Likelihood Function
The numbers in parentheses represent the standard deviation.

Table 7: Descriptive Statistics of Technical Efficiency

Region	Mean	Std. Dev.	Minimum	Maximum	Count
Africa	33.18	19.26	11.70 (Nigeria)	97.22 (Sierra Leone)	23
East Asia	79.90	11.44	66.38 (China)	98.82 (Hong Kong)	9
Latin America	77.68	14.85	54.17 (Brazil)	98.35 (El Salvador)	18
South Asia	47.13	24.82	16.92 (Myanmar)	96.58 (India)	7
West	85.54	8.49	65.75 (France)	99.27 (U.K)	23

Table 8: Output Growth Decomposition by Decade and Region (% in Parentheses)

Year	Output Growth	Capital Effect	Labor Effect	Age Effect	Education Effect	Tech. Eff. Change	Tech. Change	TFP Growth
Africa								
60-69	4.20	2.36	1.21	0.04	0.08	0.70	-1.41	0.63
	(100.0)	(56.2)	(28.8)	(1.0)	(1.9)	(16.7)	(-33.6)	(15.0)
70-79	4.08	3.49	1.36	-0.03	0.13	0.67	-1.41	-0.77
	(100.0)	(85.5)	(33.3)	(-0.7)	(3.2)	(16.4)	(-34.6)	(-18.9)
80-89	1.30	1.58	1.29	-0.17	0.14	0.63	-1.41	-1.57
	(100.0)	(121.5)	(99.2)	(-13.1)	(10.8)	(48.5)	(-108.5)	(-120.8)
60-89	3.16	2.48	1.29	-0.06	0.12	0.67	-1.41	-0.61
	(100.0)	(78.5)	(40.8)	(-1.9)	(3.8)	(21.2)	(-44.6)	(-19.3)
East Asia								
60-69	7.26	2.38	1.02	1.06	0.12	-0.62	2.11	3.86
	(100.0)	(32.8)	(14.0)	(14.6)	(1.7)	(-8.5)	(29.1)	(53.2)
70-79	7.75	4.53	1.09	0.16	0.29	-0.93	2.11	2.13
	(100.0)	(58.5)	(14.1)	(2.1)	(3.7)	(-12.0)	(27.2)	(27.5)
80-89	5.71	3.61	0.86	-0.17	0.29	-1.42	2.11	1.24
	(100.0)	(63.2)	(15.1)	(-3.0)	(5.1)	(-24.9)	(37.0)	(21.7)
60-89	6.89	3.55	0.99	0.33	0.23	-1.00	2.11	2.35
	(100.0)	(51.5)	(14.4)	(4.8)	(3.3)	(-14.5)	(30.6)	(34.1)
Latin America								
60-69	4.97	2.53	1.05	0.86	-0.08	0.83	-0.91	1.39
	(100.0)	(50.9)	(21.1)	(17.3)	(-1.6)	(16.7)	(-18.3)	(28.0)
70-79	4.76	3.74	1.18	0.09	-0.12	0.67	-0.91	-0.16
	(100.0)	(78.6)	(24.8)	(1.9)	(-2.5)	(14.1)	(-19.1)	(-3.4)
80-89	1.24	1.35	1.12	-0.32	-0.13	0.52	-0.91	-1.23
	(100.0)	(108.9)	(90.3)	(-25.8)	(-10.5)	(41.9)	(-73.4)	(-99.2)
60-89	3.61	2.54	1.12	0.19	-0.11	0.67	-0.91	-0.05
	(100.0)	(70.4)	(31.0)	(5.3)	(-3.0)	(18.6)	(-25.2)	(-1.4)
South Asia								
60-69	4.55	1.500	-0.18	0.82	-0.56	-0.59	3.71	3.23
	(100.0)	(33.0)	(-4.0)	(18.0)	(-12.3)	(-13.0)	(81.5)	(71.0)
70-79	4.11	1.95	-0.23	0.08	-0.79	-0.63	3.71	2.39
	(100.0)	(47.4)	(-5.6)	(1.9)	(-19.2)	(-15.3)	(90.3)	(58.2)
80-89	4.49	2.22	-0.29	-0.10	-0.81	-0.68	3.71	2.56
	(100.0)	(49.4)	(-6.5)	(-2.2)	(-18.0)	(-15.1)	(82.6)	(57.0)
60-89	4.38	1.90	-0.23	0.24	-0.73	-0.63	3.71	2.71
	(100.0)	(43.4)	(-5.3)	(5.5)	(-16.7)	(-14.4)	(84.7)	(61.9)
West								
60-69	5.08	3.76	0.28	0.34	0.02	0.14	-0.14	1.04
	(100.0)	(74.0)	(5.5)	(6.7)	(0.4)	(2.8)	(-2.8)	(20.5)
70-79	3.76	3.46	0.32	-0.01	0.05	0.12	-0.14	-0.02
	(100.0)	(92.0)	(8.5)	(-0.3)	(1.3)	(3.2)	(-3.7)	(-0.5)
80-89	2.55	1.82	0.26	-0.08	0.06	0.11	-0.14	0.47
	(100.0)	(71.4)	(10.2)	(-3.1)	(2.4)	(4.3)	(-5.5)	(18.5)
60-89	3.75	2.99	0.29	0.08	0.05	0.20	-0.14	0.47
	(100.0)	(79.7)	(7.7)	(2.1)	(1.3)	(5.3)	(-3.7)	(12.5)