Output Decomposition in the Presence of Input Quality Effects: A Stochastic Frontier Approach

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Yasmina Rim Limam[*], Stephen M. Miller[†] and Giampaolo Garzarelli[‡]

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Abstract

How do physical capital accumulation and Total Factor Productivity (TFP) individually add to economic growth? We approach this question from the perspective of the quality of both labor and physical capital, namely human capital and the age of physical capital. We build a unique dataset by explicitly calculating the age of physical capital for each country and each year of our time frame and estimate a stochastic frontier production function incorporating input quality in five groups of countries (Africa, East Asia, Latin America, South Asia, and West). Physical capital accumulation generally proves much more important than either the improved quality of factors or TFP growth in explaining output growth. The age of capital decreases growth in all groups except in Africa, while human capital increases growth in all groups except in East Asia.

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KEY WORDS: Age of Physical Capital, Output Growth, Stochastic Frontier, Total Factor Productivity

1 Introduction

Several contributions explain countries' rates of real output growth. However, there is no unanimous answer about the most significant determinants of such growth. The answer from growth accounting sees the separation of growth into two components: one component related to factor accumulation, most often accounted for by physical and human capital, and the other accounted for by Total Factor Productivity (TFP). These studies assume that TFP is a residual

[*]Faculté des Sciences Économiques et de Gestion de Nabeul, Nabeul, Tunisia & IPEG, SEBS, University of the Witwatersrand, P. Bag 3, WITS 2050, Johannesburg, South Africa, rim.limam@wits.ac.za, +27.11.717.8110 (Tel.), +27.11.717.8064 (Fax)

[†]Department of Economics, University of Nevada, Las Vegas, NV 89154-6005, USA, & Emeritus, Department of Economics, University of Connecticut, Storrs, USA. stephen.miller@unlv.edu

[‡]DiSSE, Sapienza – Università di Roma, Rome, Italy & IPEG, SEBS, University of the Witwatersrand, Johannesburg, South Africa. giampaolo.garzarelli@gmail.com

often associated with technological change (the so-called Solow [1956] residual), and find that TFP represents the biggest share of output growth in developed countries. Cross-country studies (chiefly in endogenous growth, [Romer, 1986; Lucas, 1988]) instead seek to explain the residual using economic variables, such as trade openness and research and development (e.g., Miller and Upadhyay 2000; Parente and Prescott, 2005). These studies present mixed results concerning the main components of growth, even though they seem to favor physical capital accumulation. This paper approaches the question about the determinants of output growth by focusing on input quality, namely the level of education of the population (human capital) for labor and the age of the capital stock for physical capital.

Human capital is recognized as an important factor for growth. Yet its influence on growth remains debated, resulting in two trends in the literature. The first trend considers human capital to be a direct input in production (e.g., Mankiw, Romer, and Weil, 1992; Islam, 1995); while the second sees it as influencing labor productivity (e.g., Benhabib and Spiegel, 1994; Koop, Osiewalski, and Steel, 2000; Turner, Tamura, and Mulholland, 2013). We follow the second trend by deeming human capital as entering production through its influence on labor productivity: labor contributes more to total output the higher is the level of human capital.

While human capital is generally acknowledged as important, less attention is given to the quality of physical capital. But exploring the quality of physical capital is equally important. For growth can arise from the employment of more capital goods or from the employment of improved capital goods (Aghion and Howitt, 2007). Most theoretical work in economic growth assumes that the quantity of physical capital stock changes over time through investment flows and depreciation – thus treating all units of capital equally. Such assumption appears unreasonable, especially considering the different economic performance of countries through time. We use the average age of physical capital to account for the quality of physical capital, and regard physical capital as contributing more to output the newer it is. We therefore build a unique data set on the average age of capital stock for 90 countries grouped into five regions (Africa, East Asia, Latin America, South Asia, and West) and over the period 1960-2007. We subsequently determine, through stochastic frontier analysis, the relative contributions of physical capital accumulation and TFP to growth in each group.

Our approach allows the assessment of different effects on growth. First, it sheds light on the relative importance of physical capital accumulation and TFP when the quality of inputs is included. Second, analogously to Gapinski (1999), it allows the separation between the purely input quantity effect from the input quality effect. Third, thanks to the inclusion of input quality, TFP growth is decomposed into input quality change, technical efficiency change, and technological change.

Our principal findings can be reported quickly. The decomposition of output growth demonstrates that physical capital accumulation generally proves much more important than either the improved quality of factors or TFP growth in explaining output growth. The age of capital decreases growth in all groups except in Africa (the older the capital, the slower the growth), while education increases growth in all groups except in East Asia. Technological change exhibits the highest effect on growth in East Asia and the lowest in Africa. Finally, our findings indicate that whenever the age of capital is significant and with the right sign, technology is improving.

The rest of the paper is organized as follows. We start by establishing context through literature and motivation (Section II), after which we calculate the capital stock and its average age (Section III). Our model is described next (Section IV), followed by our findings (Section V). The conclusion wraps up with summary and policy considerations (Section VI).

2 Context

A. *Literature*

The paper relates to two strands of existing literature. The first concerns the components of output growth, while the second deals with the importance of physical capital quality within TFP.

The strand about the components of output growth finds its roots in growth accounting (panel and cross-country), employed to test empirically Solow's growth model. Early growth accounting raises questions about the role of physical and human capital accumulation – i.e., factor accumulation – in output growth. The large unexplained residual in the Solow-model calculations suggests that factor accumulation does not fully explain output growth and that TFP accounts for the bulk of output change (Klenow and Rodríguez-Clare, 1997; Easterly and Levine, 2001). In contrast, more recent growth accounting studies reject the importance of TFP and conclude that it is factor accumulation that accounts for most cross-country income differences (e.g., Baier, Dwyer, and Tamura, 2006).

In general, growth accounting is criticized on the basis of measurement issues, such as the overestimation of physical capital accumulation, and because TFP emerges as a residual, not allowing the distinction between technological change and technical efficiency (Bosworth and Collins, 2003). In addition, the (often mechanical) method of growth decomposition does not permit direct, model-based explanations of output differences across countries (Mastromarco, Serlenga, and Shin, 2016).

The shortfalls of growth-accounting and growth-regression methods led to the search for estimation techniques that provide a more precise decomposition of the Solow residual, regularly linked to technological change. These alternative techniques include frontier analysis (Farell, 1957), originally employed to study firms' technical efficiency and subsequently, in its stochastic variant accounting for external shocks (natural calamities, terrorist attacks, wars), economic growth at country level. Similarly to the notion of world technology frontier (e.g., Acemoglu, Aghion, and Zilibotti, 2006), stochastic frontier analysis assumes that countries do not always make the best use of their inputs, implying inefficiency in production. TFP is therefore no longer limited to technological change, but also incorporates technical efficiency.

In addressing whether factor accumulation or TFP growth explains most of output growth, most early frontier applications confirm the hypothesis that it is factor accumulation and not TFP growth that explains the bulk of output growth (Kumar and Russel, 2002; Henderson and Russel, 2005; Kumbahkar and Wang, 2005; Nissan and Niroomand, 2006). More recent applications instead do not agree on an answer. For example, Makiela (2009) finds that factor accumulation captures the biggest share in explaining growth, while Pires and Garcia (2012) find that TFP growth explains a significant part of output growth.

As mentioned at the outset, this work primarily differs from previous ones by including input quality. One commonly used approach to account for the quality of physical capital employs efficient units of capital (corrected for the age effect) instead of physical ones (e.g., Hulten, 1992) ("efficient units of capital" approach). In this efficient units approach, one constructs capital series where capital depreciates physically (at a rate that can equal or differ by country or by type of capital) as well as becomes technologically obsolete. Most studies that use efficiency units focus either on applications to a single (developed) country (Shinada, 2011) or to an industry (Gittleman, Raa, and Wolff, 2006). They seem to agree, however, that the inclusion of the age effect adjusts TFP upward, and causes some smoothing of TFP.

Instead of correcting the capital stock using efficiency units of capital, we present a simple model where the productivity of capital directly depends on the age of capital, positing that physical capital can positively affect growth either through its physical amount or through its average age. The model also accounts for the quality of labor using human capital. Previous growth studies recognize the effect of human capital on labor productivity and account for it by multiplicatively increasing labor with a measure of human capital (calling this new labor measure "augmented labor"). We follow another approach. In our specification human capital does not affect the productivity of labor multiplicatively. Rather, its productivity effect is appraised through the share of labor in total output.

After building a unique dataset on the average age of physical capital for 90 countries over a significant stretch of time, we measure the comparative added value of physical capital accumulation and TFP to output growth when capital and labor quality are taken into account. In the presence of input quality effects, TFP change decomposes into changes in input quality, technical efficiency, and technology. What is more, unlike augmented labor and efficient units approaches, it allows the separation between the purely input and quality effects present in economic growth.

B. *Motivation*

The paper is motivated by the so-called embodiment hypothesis that suggests that older capital contributes less to TFP than newer capital: older capital embodies older technology, which, *ceteris paribus*, is less productive.[1] The hy-

[1] One of the *cetera* that is kept *paria* is the absence of other trade-offs that may tip the technology adoption balance. In the case of space exploration, for instance, reliable technology is more valuable than latest technology. A recent illustration is NASA's Orion Multi-Purpose Crew Vehicle (Orion MPCV)

pothesis has been tested empirically at different levels (aggregate, industry), and has not always been proven to hold (e.g., Caselli, 2005; Whelan, 2007). A common explanation given to justify this finding is that most databases already adjust for the quality of capital through prices. The same literature, however, recognizes that these adjustments may not entirely capture the improved quality of physical capital. Hence, some quality effect still may be unaccounted for. Another explanation relates to the construction of the capital stock series itself. This explanation rests on the belief that the construction of the series places too little weight on old units of investment. Consequently, it does not appropriately substantiate for the productive effects of different units of investment.

We test the embodiment hypothesis by regressing the growth of a measure of TFP against the growth of lagged investment series.[2] If the hypothesis holds, we expect the growth of more distant investment lags to exert less on current TFP growth than less distant lags. We keep the analysis simple by considering that total output is produced using physical capital and labor; and, following Caselli (2005), measure TFP as $\frac{Y}{L^{(1-\alpha)}}$, where Y is total output, L is units of labor, and α is the elasticity of output with respect to capital, which, in line with standard practice, we set equal to 1/3.

We estimate a simple cross-country OLS regression where the dependent variable, namely growth in TFP, is regressed against the growth in investment in 1965, 1975, 1985, 1995, and 2007 in the sample of 90 countries (one observation per country). To have a broader picture, we re-estimate the same cross-country regression with weights given to growth in investment. Both regressions are corrected for heteroskedasticity. We calculate the variables using data from the Penn World Tables 6.3 (PWT6.3).[3]

Table 1 displays the results, which are in line with the embodiment hypothesis. Panel A presents the regression of TFP growth against the growth of investment in 1965, 1975, 1985, 1995 and 2007. We see that different lags of investment carry different coefficients that are also generally larger for more recent lags, suggesting that more recent investment growth contributes more to TFP growth than older investment growth. Panel B of Table 1 displays the results of the OLS with weights, which are in line with those of the simple OLS: the coefficients on distant lags are generally smaller than those on more recent lags. To check the statistical difference of the coefficients, we perform a linear restrictions test on both estimations. Results show that the hypothesis that coefficients are pairwise equal is rejected at the one percent significance level for the simple OLS and at the nine percent significance level for the weighted OLS.

The bottom line of our regression exercise is that we cannot a priori reject the embodiment hypothesis, entailing that there may be a negative correlation between TFP and the age of capital stock. There is accordingly scope to more

spacecraft. See http://www.computerworld.com/article/2855604/the-orion-spacecraft-is-no-smarter-than-your-phone.html.

[2] We regress growth rates instead of levels of the investment series to avoid possible multicollinearity issues.

[3] Heston, Summers, and Aten (2009); http://www.rug.nl/research/ggdc/data/pwt/pwt-6.3.

precisely ascertain the relation between TFP and the age of the capital stock by considering the effect of the age of capital stock on productivity of capital.

3 Calcualtion of the Capital Stock and Its Average Age

This section estimates capital stocks and the average age of physical capital for the 90 countries over the period 1960-2007. The countries are grouped into 5 regions as follows: Africa (30 countries), Latin America (21 countries), East Asia (8 countries), South Asia (8 countries), and the West (23 countries). Appendix A reports the list of countries in each region.

A. *Calculating the Capital Stock*

In order to estimate the capital stock series, we first estimate the initial capital stock (1960) for each country. Then, based on that starting value, and available investment series, we use the perpetual inventory method to derive the capital stocks for the entire period.

The initial capital stock is calculated using the steady-state method (King and Levine, 1994). The method assumes that the capital-output ratio is constant in the steady state. That is, for each country, physical capital and real output grow at the same rate $\phi_t^* = dK_t/K_t = dY_t/Y_t$, where ϕ_t^* equals the steady-state growth rate, K_t equals the capital stock, and Y_t equals real GDP. Since $dK_t = I_t - \delta K_t$, then $(dK_t/K_t) = (I_t/K_t) - \delta$, where I_t equals gross investment, and δ is the depreciation rate of physical capital.[4]

We assume that δ is constant across countries and time at seven-percent per year (King and Levine 1994). Consequently, the steady-state capital-output ratio for country j is derived as follows:

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

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

$$\phi_j^* = \lambda\phi_j + (1-\lambda)\phi_w, \tag{2}$$

where $\lambda = 0.25$ is a measure of mean reversion in the growth rates (Easterly, Kremer, Pritchett, and Summers, 1993), and $\phi_w = 0.04$ equals the world growth rate over the 48-year period.

The calculation of the steady-state capital-output ratio assumes that the capital-output ratio remains fixed. We use the steady-state capital-output ratio

[4] The notation means that $dK_t = K_{t+1} - K_t$ and $dY_t = Y_{t+1} - Y_t$.

to calculate each country's initial capital stock. As the steady-state capital-output ratio applies to the initial year, the following holds:

$$K_{j,0} = \kappa_j Y_{j,0}, \tag{3}$$

where $Y_{j,0}$, and $K_{j,0}$ equal country j's initial GDP and initial capital stock (1960). The calculation of the capital stock for the remaining years uses the perpetual inventory method first developed by Harberger (1978):

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

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

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

Equation (5) produces a time-series capital stock for all countries. Investment is calculated using data on real GDP per capita, population, and the investment as a share of GDP. As before, the data are from PWT6.3.

Table 2 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 entire sample. Note how, except for East Asia during the last decade, all variables increase continuously over the period and in all regions. The West possesses the highest averages of real output and physical capital in all five decades, while Africa owns the lowest averages. The labor force, however, emerges as the highest in East Asia and the lowest in Africa.

Table 3 reports the average capital-output and capital-labor ratios per decade and per region as well as the minimum and maximum averages for countries over the entire sample. Notice how the capital-output ratio exhibits ups and downs for all groups without a clear trend. The capital-labor ratio rises up to the fourth or fifth decade depending on the region and then starts decreasing without a specific trend. The West ranks first in terms of both ratios while Africa and South Asia have the lowest capital output and capital labor ratios, respectively.

B. *Calculating the Average Age of the Capital Stock*

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

$$V_t = WAA_t = \left[\textstyle\sum_{i=1}^{t}(t-i)(1-\delta)^{t-1}I_{i-1} + (\bar{V}+t)(1-\delta)^{t}K_0\right]/K_t \tag{6}$$

where V equals the age of the capital stock, $\bar{V}$ equals the average age of the steady-state capital stock, and WAA equals the weighted aggregate age of the capital stock, where investment provides the weights.[5] Consequently, the

[5] The initial average age assumes a steady state situation in 1960.

average age of capital depends only upon the level of investment, the depreciation rate, and the average age of the steady-state capital stock. 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 regions that constitute the final analysis.

Further discussion of equation (6) proves important. First, note that the steady-state capital stock in period zero (i.e., K_0 by assumption) exhibits an average age of $\bar{V}$. As we move one year ahead in time, the initial capital stock depreciates and ages by one year, which continues for each additional year. Thus, we write $(\bar{V}+t)(\bar{V}-\delta)^t K_0$ to capture the weighted age of the initial capital stock after t years, which appears as the last term in the brackets in (6). For each additional period beyond period zero, we add investment (i.e., I_i) to the capital stock. Investment in period i only appears in the capital stock in period $(i+1)$ with age equal to one. Then moving to time period $t > i$, we write the weighted age of the capital stock from the *i-th* period as $\sum_{i=1}^{t}(t-i)(1-\delta)^{t-1}I_{i-1}$, which appears as the first term in the brackets in (6). For example, when $i = t{-}1$, then the weighted age equals I_{i-1}.

Second, the average age of the steady-state capital stock gets calculated as follows. Compare the age of the capital stock at time zero and one. At time zero, we assume that the capital stock equals the steady-state value. Thus, the average age equals $\bar{V}$. In period one, the stock of capital in period zero becomes one year older [i.e., $(\bar{V}+1)$] and it depreciates by δ. The investment in period zero (i.e., I_0) carries on as capital in period one with age equal to zero. Thus, the average age of the capital stock in period one equals the following expression:

$$V_1 = \left[(\bar{V}+1)(1-\delta)K_0\right]/K_1 \tag{7}$$

where

$$K_1 = (1-\delta)K_0 + I_0 \tag{8}$$

Assuming that the investment in period one exactly kept the capital stock at its steady-state level in period one, then $V_1 = \bar{V}$. Substituting (8) into (7) and setting $V_1 = \bar{V}$ produces the following solution for $\bar{V}$:

$$\bar{V} = (1-\delta)(K_0/I_0) \tag{9}$$

Since (K_0/I_0) equals the steady-state capital-investment ratio, we substitute from equation (1) to obtain the following outcome:

$$\bar{V} = (1-\delta)(\delta + \phi_j^*), \tag{10}$$

where $\phi^*$is calculated as in (2) and takes a different value for each country. This leads to a different average age of the initial capital stock for each country. Table 4 reports the average age of capital for each decade and for the 48-year period for each group. Over the period, Africa exhibits the highest age of capital (8.99 years) and East Asia the lowest (6.64 years). The average age of capital is 8.77, 8.26, and 8.66 years in Latin America, South Asia and the West, respectively. On a decade-by-decade basis, the average age of capital equals the highest in the first decade in East Asia and South Asia while it is the highest in the fourth decade in Latin America and the West. In Africa, the average age of capital is at its highest in the last decade. East Asia experiences the fastest decline in the average age of its capital stock in the first three decades before the average age starts increasing again in the 1990s and 2000s. We expect this outcome, since East Asian countries largely focused on industrialization and modernization of their economies during the first three decades of our study (1960-1990). The policy shift of Hong Kong and Singapore from import substitution to export promotion strategies and their high investment rates during the 1960s helps to explain their lowest average age of capital.

Similarly, Table 5 provides information on the mean years of education by decade and by region. It shows that the level of education increases across the decades for all groups, the only exception is the sharp decrease experienced by East Asia in the years 2000-07. East Asia experiences the highest mean years of education over the 48-year period followed by Latin America, West, South Asia, and Africa.

4 Model

Stochastic frontier 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 (Aigner, Lovell, and Schmidt, 1977; Meusen and van den Broeck, 1977). The distance between the frontier and the actual production point measures technical inefficiency. In this context, the Solow residual reflects not only technological change, but also country specific variables that influence a country's success in producing close to its best-practice output.

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 of in terms of the three components: efficiency change, technological change, and input change.

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

$$Y_{it} = A_t K_{it}^{\beta_{1it}} L_{it}^{\beta_{1it}}, \tag{11}$$

where Y_{it}, K_{it}, and L_{it} represent country i's real GDP, physical capital stock, and labor at time t. A_t equals $Ae^{\zeta t}$, where ζ measures the rate of technological change. That is to say that, throughout, the t in ζt represents a simple time trend accounting for technological change from technology affecting production that is not captured by the age of capital. The parameters β_{1it} and β_{2it} measure the elasticities of output with respect to capital and labor.

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 capital age and human capital, respectively. Thus,

$$\beta_{1it} = \alpha_1 + \alpha_2 V_{it}, \tag{12}$$

and

$$\beta_{2it} = \omega_1 + \omega_2 H_{it} \tag{13}$$

where V_{it} represents country i's average age of physical capital 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 older technology, one expects that the lower the average age, the more productive the capital stock. Similarly, the more educated workers are, the higher the productivity of labor. Consequently, we expect that the sign of α_2 is negative, and that the sign of ω_2 is positive.

After substituting equations (12) and (13) into equation (11) and after taking natural logarithms, (11) becomes:

$$\ln Y_{it} = \ln A + \alpha_1 \ln K_{it} + \alpha_2 V_{it} \ln K_{it} + \omega_1 \ln L_{it} + \omega_2 H_{it} \ln L_{it} + \xi t + v_{it} - u_{it}, \tag{14}$$

where v_{it} are independently and identically distributed random errors, $iid \sim N(0, \sigma_v^2)$, and u_{it} are distributed independently of v_{it} and follow a normal distribution, that is $u_{it} \sim N(\mu, \sigma_v^2)$.

We model the one-sided error term as:

$$u_{it} = \eta_{it} u_i = \exp[-\eta(t-T)]u_i, \qquad (t = 1, ..., T; i = 1, 2, ...N), \tag{15}$$

where η captures the rate of decline in technical inefficiency (Battese and Coelli, 1992). Thus, the technical efficiency measures for every country and every year are calculated as:

$$\widehat{TE}_{it} = \exp(-u_{it}) \tag{16}$$

Battese and Corra (1977) suggest that to facilitate hypothesis testing σ_u^2 and σ_v^2 be replaced by $\sigma^2 = \sigma_u^2 + \sigma_v^2$ and $\gamma = \sigma_u^2/(\sigma_v^2 + \sigma_u^2)$. Under this parameterization, γ measures, between zero and one, the share of technical efficiency in explaining the error variation.

We estimate equations (14) and (15) for each group and for the period 1960-2007.[6] Data on V and K are from our previous calculations, while L is calculated from the PWT6.3 data on real GDP and real GDP per worker. To approximate the level of human capital, we use the mean years of secondary education as calculated by the Barro-Lee Educational Attainment Dataset.[7]

[6] We use FRONTIER Version 4.1: http://www.uq.edu.au/economics/cepa/frontier.php.

[7] The data in the Barro-Lee Educational Attainment Dataset (Barro and Lee, 2013) are presented at 5-year intervals (http://www.barrolee.com/). Since our time series from 1960 to 2007 requires yearly data, we use the value of the reported year for the subsequent years in each interval (Wang and Wong, 2012). For example, the number for 2000 will be repeated for all the years from 2000 to 2004.

We perform several hypotheses tests concerning the existence of regional frontiers versus a single world frontier, and the existence and the distribution of the efficiency term, employing log-likelihood tests. We find that the regional frontiers exhibit significantly different technologies, and aggregation into a world technology does not seem justified. We further find that the stochastic frontier significantly dominates the OLS model in all regions and the half-normal distribution dominates the truncated normal in all regions except for Africa. Finally, we test whether technical efficiency is time varying or time invarying. We find that the time-varying technical efficiency dominates in every region, except for Africa. See Table B.1 in Appendix B.

We now consider the time series properties of the data. Panel data require stationarity of the series. If the model is estimated and the series are non-stationary, then the issue of false correlation among the series may arise and the estimated production function would be spurious. In stochastic frontier analysis this implies that the inefficiency term is meaningless and inaccurate. In the absence of level stationarity, one should consider first differences. If the latter are all stationary, then there could be a long run relationship in the series (i.e., there is cointegration), in which case we can proceed with data analysis. We employ the panel unit root test of Im, Pesaran, and Shin (2003) to check for stationarity in $\ln Y$, $\ln K$, $\ln L$, $V \ln K$, and $H \ln L$. Results indicate that most of the series are non-stationary in level (Table B2, Panel A) but stationary in first difference (Table B2, Panel B). The Johansen Fisher test for panel cointegration rejects the null hypotheses of no cointegration between the series at the one percent level for all groups (Table B3). This result implies that even though the level series are not stationary, they follow a common trend in the long run, meaning that a long run relationship exists between them and level analysis can be performed. This sets the ground for our stochastic frontier analysis.

5 Findings

Table 6 displays the results of the regional stochastic frontier estimations from (14), where the frontier specification for each region is based on the hypothesis tests as reported in Table B.1 in Appendix B. Results show that the coefficients on capital and labor prove significantly positive in all regions. The coefficients on the average age of capital interaction term prove significantly negative in East Asia, Latin America, and the West suggesting that the older capital stock exhibits lower productivity in these three regions. The coefficient is negative but insignificant in Africa, which suggests that the age of the capital stock does not affect productivity in Africa. Finally, the coefficient is positive and significant in South Asia, which is an exception to our expectation. The coefficients, however, do not produce sizeable effects, as we shall see later.

The coefficients on the human capital interaction term prove significantly positive in Africa, South Asia and West and positive and insignificant in Latin America. In East Asia, the coefficient is significant and negative. This result indicates that with the exception of East Asia, higher educational attainment generated more productive labor. The coefficients on the time trend prove significant (even though at different levels) and positive in East Asia, Latin America, and the West, but significantly negative in Africa and South Asia. That is, technological change occurs in those regions where the average age of capital is negatively related to economic growth. This indicates that whenever the age of capital is significant and with the right sign, technology improves growth. The last four rows of Table 6 show the results related to the inefficiency term. Technical efficiency significantly improves in East Asia and the West but significantly deteriorates in Latin America and South Asia. The estimated coefficient for γ for Africa, East Asia, Latin America, South Asia, and the West are, respectively, 0.92, 0.97, 0.94, 0.033, and 0.97. These results indicate that technical efficiency explains most of the error variations in Africa, East Asia, Latin America and West, but does not explain much of the error term in South Asia.

Table 7 reports the results for the technical efficiency estimates – means, standard deviations, and minimum and maximum values. South Asia possesses the highest average efficiency (0.89) while Africa exhibits the lowest efficiency (0.31). Uganda dominates within Africa with the highest efficiency (0.97) while Tanzania exhibits the lowest efficiency (0.13). Most other African countries exhibit low efficiencies as compared to Uganda, leading Africa to exhibit the highest variability (0.17). In Latin America, Venezuela shows the highest efficiency (0.99) while Nicaragua shows the lowest efficiency (0.48). In the West, the average efficiency varies from the low of 0.31 in Cyprus to 0.99 in the United States. Finally, in East Asia the average efficiency varies from the low of 0.25 in China to 0.97 in Hong Kong.

To calculate the output elasticity of capital, we differentiate (14) with respect to the natural logarithm of capital to derive the output elasticity of capital:

$$\frac{\partial \ln Y_{it}}{\partial \ln K_{it}} = \alpha_1 + \alpha_2 V_{it} \tag{17}$$

Similarly, the output elasticity of labor is:

$$\frac{\partial \ln Y_{it}}{\partial \ln K_{it}} = \omega_1 + \omega_2 H_{it} \tag{18}$$

With different values of V and H over countries and over time, equations (17) and (18) 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. Table 8 lists the summary statistics for the output elasticities with respect to capital and labor. The capital elasticity is highest in the West and lowest in East Asia while labor elasticity is highest in Africa and lowest in the West. Moreover, the variability of the labor elasticity exceeds that of the capital elasticity in all groups except in South Asia.

We next decompose output growth into input growth, input quality change, technical 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 (14) in growth rates becomes:

$$\dot{\widehat{Y}}/\widehat{Y} = (\alpha_1+\alpha_2 V)\frac{\dot{K}}{K}+(\omega_1+\omega_2 H)\frac{\dot{L}}{L}+\alpha_2 V \ln K\frac{\dot{V}}{V}+\omega_2 H \ln L\frac{\dot{H}}{H}+\frac{\dot{TE}}{TE}+\zeta \quad (19)$$

where dots over variables represent time derivatives and $\hat{Y}$ is the estimated value of Y. We approximate the growth rate of variable X by the natural logarithmic difference between t and $t-1$. That is,

$$\frac{\dot{X}}{X} = \ln X_{it} - \ln X_{it-1}, \qquad \text{where } X = Y, K, L, V, H, \text{ and } TE. \qquad (20)$$

Equation (19) illustrates that the percentage change in output includes: i) the change in the units of capital; ii) the change in the units of labor; iii) the change in the average age of capital; iv) the change in the mean years of education; v) the efficiency change, and vi) the technological change.

The third and fourth terms on the right hand side of equation (19) 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.[8] We calculate the different components of output growth for the five regional groups.

Table 9 reports the results of the output growth decomposition by region over the entire period as share in total growth. (Table B.4 in Appendix B presents the decomposition by decade and by region.) Results indicate that physical capital, labor, technical efficiency, and technological change all contribute importantly to output growth. Their strengths, however, vary across regions. The contribution to output growth of physical capital achieves its largest values in Latin America, where it accounts for 154.85 percent of total output growth, and its lowest value in East Asia where it explains only 41.66 percent of output growth.[9] Meanwhile, the contribution of labor to output growth achieves its highest value in Africa where it accounts for almost 45 percent of total output growth, and its lowest values in Latin America where it explains 7.20 percent of total output growth. In all regions, the findings show that the contribution of physical capital to output growth far exceeds that of labor. Labor "quantity appears to be a weak foundation on which to build strong growth" (Gapinski, 1999, p. 125).

[8] These assertions implicitly assume that the effects of the age of capital and the educational attainment achieve their expected outcomes.

[9] The percentages for Latin America are frequently large because the estimated growth rate is low with significant random errors.

Looking at the contribution of technological change to growth, we notice that technological change possesses the highest share in total output growth in East Asia at 39.80 percent, and the lowest in Africa at –28.81 percent. In addition to its negative effect in Africa, technological change seems to affect growth negatively in South Asia as well. These results correspond with those of Kerekes (2011), who argues that technological change contributes to growth in high and middle income countries, but not in low income countries. Regarding technical efficiency, results show that technical efficiency change exhibits the largest effect on output growth in South Asia at 19.24 percent, and the smallest effect in Latin America at –39.23 percent.

Narrowing our focus within the output growth determinants to include input quality reveals that quantity exceeds quality for both capital and labor. To illustrate, in the West, for the entire sample, the total output growth equals 3.40 percent over the period. This rate includes an increase in physical capital of 2.27 percent, which constitutes 66 percent of total output growth, and the quality of capital reduces growth by 0.04 percent, or by –1.24 percent of total output growth. Moreover, in the West, labor explains 10 percent of total output growth, while the quality of labor increases growth by 4.47 percent. Gapinski (1999) correlates well with our results. He finds that, with the exception of Argentina, Brazil, Mexico, and Venezuela (his Latin Rim group), all other country groups in his analysis rank international trade, capital quantity, and labor quantity as the top three determinants of output growth while capital quality and labor quality equal the bottom two forces, but by a wider margin for capital. By taking a closer look at the quality effect, we notice that both human capital and the age of physical capital affect growth in the expected direction in four out of the five groups. The share of human capital in total growth is positive in all regions except in East Asia; while the share of the age of capital in growth is negative in all regions except in Africa (the higher the average age of physical capital, the lower the growth of output). We notice that human capital exerts a bigger effect on growth than the age of capital in most groups indicating that the quality of labor takes over the quality of physical in most groups. We note, however, that it is in South Asia that the quality of inputs has the highest positive effects on growth.

Whether factor accumulation or TFP growth contributes more to output growth remains perhaps the most controversial question in growth theory. Solow (1956) argues that the residual and not factor accumulation accounts for the bulk of output growth in the US. King and Levine (1994) and Easterly and Levine (2001) also find that the residual accounts for most of the income and output growth differences across countries. Kumar and Russel (2002) and Nissan and Niroomand (2006) instead argue in favor of factor accumulation. To evaluate the role of TFP in output growth, we calculate the share of TFP growth in total output growth for each group as the difference between the rate of change of real product and the rate of growth of inputs. Applying this definition to (10), the change in TFP can be calculated as follows:

$$\frac{T\dot{F}P}{TFP} = \dot{\hat{Y}}/_{\hat{Y}} - \left[(\alpha_1 + \alpha_2 V)\frac{\dot{K}}{K} + (\omega_1 + \omega_2 H)\frac{\dot{L}}{L} \right]. \tag{21}$$

The last column of Table 9 shows the growth in TFP and its contribution to output growth. The share of TFP growth reaches the highest percentages in East Asia and the West where TFP growth contributes 37.38 and 23.28 percent of total output growth while it reaches its lowest in Latin America and Africa with contributions to growth of –62.05 and –19.20 percent, respectively. Comparing the last column of Table 9 (*TFP*) to the third (K), we notice that capital accumulation overtakes TFP by far in all regions. This result supports the claim that it is physical capital accumulation and not TFP that explains most of growth.

6 Conclusion

This paper contributes to the growth literature by examining the relative effects of factor accumulation and TFP improvement on output growth, taking into account the quality of inputs. We consider that the productivity of physical capital increases the younger is the capital; while the productivity of labor is higher the more educated workers are. We estimate the average age of physical capital for 90 countries (grouped into five regions) and over the period 1960-2007. We find that the role of the age of the physical capital stock is not irrelevant to pinpoint productivity: stochastic frontier estimation reveals that the coefficient on the average age of physical capital proves negative and significant in three out of five groups. The negative effect of the average age of physical capital indicates that in these regions older capital exhibits lower productivity. Human capital possesses a positive and significant effect in all groups except in East Asia. The negative sign on human capital in East Asia probably reflects the sharp decline in the average years of education in this group in the years 2000.

The decomposition of output growth demonstrates that, in all regions, physical capital growth proves more important than either the improved quality of factors or total factor productivity growth in explaining output growth. This result is in line with the claim that physical capital accumulation is the main driver of growth. Physical capital shows the highest share in Latin America, where it explains about 154.85 percent of total growth, and the lowest in East Asia, where it explain about 41.66 percent of output growth. Technological change exerts the highest effect on growth in East Asia, where it explains 39.80 percent of total growth, and the lowest in Africa, where it contributes negatively to growth with a share in total growth of –28.81 percent.

Two normative considerations naturally emerge from our study. The first regards the average age of the physical capital stock. Our growth decomposition shows that the age of physical capital decreases growth in four out of five groups (even if this effect is relatively small). This result hints that the old age of physical capital in these groups can be an obstacle to growth. To enhance growth, these groups should invest in newer physical capital that embeds more recent technology. The second normative consideration is about the role of technological change in developing countries. Africa and South Asia are the only two groups where the contribution of technological change to total output growth is negative. These are also the groups with the lowest average level of education. This indicates that there is an absence of human capital to successfully adopt and absorb foreign technology. It seems sensible for countries in these two groups to invest more in education if they want foreign technology to translate into growth.

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Table 1: OLS Regressions, TFP Growth as Dependent Variable

Variable	Coefficient
Panel A: Simple OLS	
Constant	0.006 (2.10)
*GInv*07	9.268 (1.98)
*GInv*95	0.210 (2.30)
*GInv*85	–0.059 (–0.67)
*GInv*75	0.013 (0.29)
*GInv*65	–0.035 (–2.02)
R^2	0.45
Panel B: OLS with Weights	
Constant	0.006 (2.17)
*GInv*07	0.284 (2.18)
$(1 - \delta)^{12}GInv95$	0.502 (2.08)
$(1 - \delta)^{22}GInv85$	–0.30 (–0.69)
$(1 - \delta)^{32}GInv75$	0.137 (0.29)
$(1 - \delta)^{42}GInv65$	–0.73 (–2.12)
R^2	0.42

Notes: $N = 90$. *GInv* is growth in investment, and the number attached to it is the year. δ is the depreciation rate that is set equal to seven percent. The numbers in parentheses are *t*-statistics.

Table 2: Average Value of *Y*, *K*, and *L* by Decade and by Region (90 countries)

Region	60s	70s	80s	90s	00-07	Average 60-07	Minimum	Maximum
				Panel A: Y (in 2005 US $ billions)				
Africa	13.85	21.42	31.51	42.23	57.34	33.27	1.15 (Gambia, The)	261.06 (South Africa)
East Asia	172.56	356.32	612.72	1101.02	560.66	560.66	62.92 (Singapore)	2468.42 (China)
Latin America	54.50	99.79	137.79	174.07	223.51	137.93	8.75 (Nicaragua)	983.70 (Brazil)
South Asia	112.93	178.35	285.06	460.10	713.63	350.01	6.74 (Papua New Guinea)	1512.14 (India)
West	133.51	211.35	270.76	346.36	2176.75	627.74	5.66 (Iceland)	6874.71 (U.S.)
				Panel B: K (in 2005 US $ billions)				
Africa	17.28	28.28	51.15	61.76	74.53	46.60	0.85 (Uganda)	428.77 (Algeria)
East Asia	405.02	853.27	1576.30	2940.43	1443.75	1443.75	205.50 (Singapore)	8388.42 (Japan)
Latin America	95.78	167.09	271.31	332.06	429.17	259.08	12.57 (Haiti)	2639.85 (Brazil)
South Asia	144.72	215.51	374.48	636.36	987.64	471.74	11.57 (Papua New Guinea)	1939.82 (India)
West	338.42	558.80	763.35	992.07	5030.12	1536.55	18.58 (Iceland)	15316.46 (U.S.)
				Panel C: L (in millions)				
Africa	2.38	2.97	3.97	5.36	6.85	4.31	0.38 (Gabon)	14.31 (Egypt)
East Asia	54.99	69.49	88.85	106.97	80.07	80.07	1.40 (Singapore)	569.90 (China)
Latin America	3.56	4.80	6.33	8.84	11.38	6.98	0.45 (Trinidad & Tobago)	91.35 (Brazil)
South Asia	36.27	44.96	57.56	72.43	88.30	59.90	1.42 (Papua New Guinea)	292.74 (India)
West	4.85	5.28	5.84	6.43	36.30	11.74	0.11 (Iceland)	109.03 (U.S.)

Note: The minimum and maximum values are based on individual country averages.

Table 3: Average *K/Y* and *K/L* by Decade and by Region (90 countries)

Region	60s	70s	80s	90s	00-07	Average 60-07	Minimum	Maximum
Panel A: Capital-Output Ratio (K/Y)								
Africa	1.09	1.11	1.29	1.22	1.15	1.17	0.06 (Uganda)	3.96 (Algeria)
East Asia	2.30	2.03	2.30	2.52	2.29	2.29	1.48 (Taiwan)	3.40 (Singapore)
Latin America	1.83	1.81	2.18	2.13	2.12	2.02	1.18 (Haiti)	3.28 (Jamaica)
South Asia	1.27	1.21	1.39	1.42	1.48	1.35	0.81 (Bangladesh)	1.64 (Papua New Guinea)
West	2.69	2.82	2.96	2.91	2.53	2.78	2.10 (United Kingdom)	3.51 (Cyprus)
Panel B: Capital-Labor Ratio (K/L)								
Africa	7.36	10.06	12.95	11.81	11.99	10.83	0.11 (Uganda)	67.89 (Algeria)
East Asia	21.70	34.33	57.53	92.86	51.60	51.60	6.39 (China)	133.05 (Japan)
Latin America	26.99	33.53	39.42	36.34	38.36	35.22	5.17 (Haiti)	86.74 (Trinidad & Tobago)
South Asia	4.68	5.96	8.43	10.16	11.46	8.14	2.96 (Bangladesh)	13.46 (Philippines)
West	76.40	111.14	134.75	154.03	149.26	125.12	72.58 (Portugal)	200.63 (Luxembourg)

Note: The minimum and maximum values are based on individual country averages.

Table 4: Average Age of Capital (*V*) in Years, by Decade and by Region (90 countries)

Decade Region	60s	70s	80s	90s	00-07	Average 60-07	Minimum	Maximum
Africa	8.94	8.32	8.38	9.46	9.85	8.99	7.70 (Tunisia)	11.06 (Congo, Dem. Rep. of)
East Asia	7.67	6.64	6.11	6.13	6.64	6.64	5.84 (Japan)	7.14 (China)
Latin America	8.61	8.13	8.30	9.46	9.36	8.77	7.72 (Dominican Rep.)	9.96 (Haiti)
South Asia	9.03	8.71	7.60	7.90	8.05	8.26	7.70 (Pakistan)	9.34 (Bangladesh)
West	8.29	7.90	8.79	9.30	9.00	8.66	7.66 (Israel)	9.80 (France)

Note: The minimum and maximum values are based on individual country averages.

Table 5: Mean Years of Education (*H*) by Decade and by Region (90 countries)

Decade Region	60s	70s	80s	90s	00-07	Average 60-07	Minimum	Maximum
Africa	0.22	0.39	0.67	1.06	1.31	0.73	0.07 (Mozambique)	2.05 (Ghana)
East Asia	1.10	1.54	2.22	2.79	1.91	1.91	0.70 (Thailand)	3.22 (Japan)
Latin America	0.57	0.89	1.38	1.78	2.19	1.36	0.52 (Guatemala)	2.24 (Chile)
South Asia	0.35	0.59	0.89	1.26	1.60	0.94	0.50 (Nepal)	1.47 (Sri Lanka)
West	0.35	0.59	0.89	1.26	1.60	0.94	1.23 (Portugal)	4.70 (U.S.)

Note: The minimum and maximum values are based on individual country averages.

Table 6: Frontier Results

Variables	Africa	East Asia	Latin America	South Asia	West
Panel A: Production Function					
Intercept	2.9121*** (9.16)	5.7887*** (14.98)	3.8947*** (14.84)	3.234*** (17.58)	4.6335*** (12.47)
$\ln K$	0.6238*** (32.43)	0.4112*** (11.62)	0.5608*** (31.52)	0.5835*** (31.48)	0.6417*** (32.39)
$\ln L$	0.6014*** (28.77)	0.5723*** (14.51)	0.4848*** (21.58)	0.4267*** (24.8)	0.2696*** (9.99)
$V\ln K$	0.0002 (0.76)	–0.0024*** (–11.18)	–0.0015*** (–5.45)	0.0014*** (5.13)	–0.0017*** (–8.01)
$H\ln L$	0.0123*** (6.55)	–0.0045*** (–2.79)	0.003 (1.21)	0.018*** (8.37)	0.0031*** (4.65)
T	–0.0086*** (–8.28)	0.0252* (15.66)	0.0035*** (2.67)	–0.0081*** (–5.58)	0.0011* (1.92)
Panel B: One-Sided Error-Term					
η	0	0.0039*** (4.05)	–0.0186*** (–10.02)	–0.0682*** (6.97)	0.011*** (8.12)
LLF	280.23	303.91	620.53	329.43	1259.44
$\sigma^2 = \sigma_u^2 + \sigma_v^2$	0.3631*** (5.72)	0.3645** (2.41)	0.2597*** (3.01)	0.01*** (12.51)	0.2003** (2.28)
$\gamma = \sigma_u^2 / (\sigma_v^2 + \sigma_u^2)$	0.9055*** (7.06)	0.971*** (76.05)	0.9401*** (46.92)	0.0331 (0.85)	0.9741*** (83.47)

Notes: The frontier specification for each region is based on the hypothesis tests as reported in Table B.1 in Appendix B. LLF stands for log-likelihood function. η is for Africa. The numbers in parentheses are *t*-statistics. *** Significant at the 1%; ** Significant at the 5%; * Significant at the 10%.

Table 7: Descriptive Statistics of Technical Efficiency

Region	Mean	Standard Deviation	Minimum	Maximum	Sample Size
Africa	0.31	17.34	0.13 (Tanzania)	0.97 (Uganda)	30
East Asia	0.69	0.25	0.25 (China)	0.97 (Hong Kong)	8
Latin America	0.77	0.15	0.48 (Nicaragua)	0.99 (Venezuela)	21
South Asia	0.89	4.59	0.83 (India)	0.97 (Bangladesh)	8
West	0.61	0.15	0.31 (Cyprus)	0.99 (U.S.)	23

Table 8: Capital and Labor Elasticities

Region	Mean	Standard Deviation	Minimum	Maximum	Sample Size
		Panel A: Elasticity of Capital			
Africa	0.625	0.0003	0.624	0.628	30
East Asia	0.394	0.0036	0.385	0.406	8
Latin America	0.546	0.0021	0.540	0.551	21
South Asia	0.585	0.0741	0.592	0.602	8
West	0.626	0.0015	0.622	0.630	23
		Panel B: Elasticity of Labor			
Africa	0.611	0.0089	0.601	0.641	30
East Asia	0.562	0.0057	0.551	0.571	8
Latin America	0.488	0.0022	0.485	0.495	21
South Asia	0.443	0.010	0.427	0.475	8
West	0.278	0.0036	0.271	0.286	23

Table 9: Output Growth Decomposition by Region (Share in Total Growth)

Variables	$\hat{Y}$	*K*	*L*	*V*	*H*	*TE*	*T*	*K + L*	*V + H*	*TFP*
Region										
Africa	100	69.66	49.54	0.28	9.32	0.00	–28.81	119.20	9.61	–19.20
East Asia	100	41.66	20.96	–1.08	–4.19	2.86	39.80	62.62	–5.28	37.38
Latin America	100	154.85	7.20	–52.25	2.15	–39.23	27.28	162.05	–50.09	–62.05
South Asia	100	61.08	23.94	–0.20	14.37	19.24	–18.43	85.02	14.07	14.98
West	100	66.64	10.08	–1.24	4.47	17.11	2.94	76.72	3.23	23.28

APPENDIX A: SAMPLE

List of Countries by Region

Africa (30 countries): Algeria, Benin, Botswana, Burundi, Central African Republic, Congo (Democratic Republic of), Côte d'Ivoire, Egypt, Gabon, Gambia (The), Ghana, Kenya, Lesotho, Malawi, Mali, Mauritania, Mauritius, Morocco, Mozambique, Namibia, Niger, Rwanda, Senegal, Sierra Leone, South Africa, Tanzania, Tunisia, Uganda, Zambia, Zimbabwe.

East Asia (8 countries): China, Hong Kong, Japan, Korea (Republic of), Malaysia, Singapore, Taiwan, Thailand.

Latin America (21 countries): Argentina, Bolivia, Brazil, Chile, Colombia, Costa Rica, Dominican Republic, Ecuador, El Salvador, Guatemala, Haiti, Honduras, Jamaica, Mexico, Nicaragua, Panama, Paraguay, Peru, Trinidad and Tobago, Uruguay, Venezuela.

South Asia (8 countries): Bangladesh, India, Indonesia, Nepal, Pakistan, Papua New Guinea, Philippines, Sri Lanka.

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

APPENDIX B: ADDITIONAL TABLES

Table B.1: Results of Hypothesis Testing

Region	χ^2-statistic	$\chi^2_{0.99}$	Decision
Panel A: Global versus Regional Frontier; H_0: Groups Exhibit Different Production Frontiers			
—	–2363.5	42.98	Fail to reject H_0
Panel B: Stochastic Frontier versus OLS; H_0: $\gamma=\mu=\eta=0$			
Africa	2142	11.34	Reject H_0
East Asia	394	11.34	Reject H_0
Latin America	941	11.34	Reject H_0
South Asia	163	11.34	Reject H_0
West	1097	11.34	Reject H_0
Panel C: Half-normal versus Truncated Normal; H_0: $\mu=0$			
Africa	11.9	6.63	Reject H_0
East Asia	1.12	6.63	Fail to reject H_0
Latin America	0.6	6.63	Fail to reject H_0
South Asia	0.98	6.63	Fail to reject H_0
West	4.56	6.63	Fail to reject H_0
Panel D: Time Varying versus Time Unvarying; H_0: $\eta=0$			
Africa	–35	6.63	Fail to reject H_0
East Asia	61	6.63	Reject H_0
Latin America	739	6.63	Reject H_0
South Asia	64	6.63	Reject H_0
West	174	6.63	Reject H_0

Table B.2: Unit Root Test

Regions \ Variables	ln*Y*	ln*K*	ln*L*	*V*ln*K*	*H*ln*L*
	Panel A: Variables in Levels				
Africa	–0.380	–0.521	–2.322	–1.073	–0.093
	(0.352)	(0.301)	(0.010)	(0.141)	(0.463)
East Asia	3.726	–1.577	5.308	–0.426	–1.830
	(0.999)	(0.057)	(1.000)	(0.350)	(0.033)
Latin America	0.396	–2.629	4.013	–3.004	–2.462
	(0.654)	(0.004)	(1.000)	(0.001)	(0.007)
South Asia	1.518	1.779	1.892	–1.220	–2.324
	(0.935)	(0.962)	(0.971)	(0.111)	(0.011)
West	–2.766	–2.986	–0.446	–2.759	–3.538
	(0.003)	(0.001)	(0.327)	(0.003)	(0.001)
	Panel B: Variables in First Difference				
Africa	–33.360	–3.429	–19.382	–3.921	–29.165
East Asia	–11.709	–2.484	–5.581	–3.835	–14.675
Latin America	–15.539	–3.258	–13.070	–3.945	–23.872
South Asia	–16.343	–0.781	–8.627	–1.763	–14.641
		(0.217)		(0.039)	
West	–18.606	–3.334	–13.355	–4.138	–23.881

Notes: The Im, Pesaran and Shin (2003) unit-root test has H_0: non-stationarity in the series. The number in parentheses corresponds to the *p*-value. For Panel B, except for the two reported in parentheses, the *p*-values are all < 0.001.

Table B3: Cointegration Test

Hypothesized No. CE(s)	Fisher Statistic (from trace test)	Fisher Statistic (from max-eigenvalue test)
Panel A: Africa		
None	780.6	367
At most 1	468.3	255.5
At most 2	261.2	144.9
At most 3	158.5	117.9
At most 4	92.66 (0.0043)	92.66 (0.0043)
Panel B: East Asia		
None	299.4	161.5
At most 1	168.8	81.72
At most 2	102.3	54.22
At most 3	60.43	45.00
At most 4	31.54 (0.0115)	31.54 (0.0115)
Panel C: Latin America		
None	516.5	295
At most 1	264.8	134.9
At most 2	154.8	84.68
At most 3	99.80	70.46 (0.0039)
At most 4	64.98 (0.0130)	64.98 (0.0130)
Panel D: South Asia		
None	176.8	106.4
At most 1	88.36	38.53 (0.0013)
At most 2	58.46	33.71 (0.0059)
At most 3	34.82 (0.0042)	23.47 (0.1018)
At most 4	25.21 (0.0662)	25.21 (0.0662)
Panel E: West		
None	654.9	365.4
At most 1	341	157.2
At most 2	212.4	108.4
At most 3	140	94.54
At most 4	89.24	89.24

Notes: Results are from Johansen Fisher Panel Cointegration Test. Probabilities are computed using asymptotic Chi-square distribution. Except for those reported in parentheses, the *p*-values are all < 0.001.

Table B.4: Output Growth Decomposition by Decade and by Region in Percent (Share in Total Growth in Parentheses)

Year	$\dot{\hat{Y}}/\hat{Y}$	$(\alpha_1+\alpha_2 V)\frac{\dot{K}}{K}$	$(\omega_1+\omega_2 H)\frac{\dot{L}}{L}$	$\alpha_2 V \ln K \frac{\dot{V}}{V}$	$\omega_2 H \ln L \frac{\dot{H}}{H}$	$\frac{\dot{TE}}{TE}$	ξ	$\frac{\dot{TFP}}{TFP}$
				Panel A: Africa				
60-69	1.96 (100)	1.52 (77.52)	1.23 (62.83)	0.02 (0.95)	0.09 (4.72)	0.00 (0.00)	–0.90 (–46.01)	–0.79 (–40.34)
70-79	4.15 (100)	3.53 (85.05)	1.44 (34.69)	–0.04 (–0.94)	0.12 (2.85)	0.00 (0.00)	–0.90 (–21.66)	–0.82 (–19.75)
80-89	3.32 (100)	2.03 (61.07)	1.91 (57.50)	0.05 (1.42)	0.24 (7.08)	0.00 (0.00)	–0.90 (–27.08)	–0.62 (–18.58)
90-99	2.66 (100)	1.52 (57.21)	1.80 (67.64)	0.03 (1.17)	0.21 (7.85)	0.00 (0.00)	–0.90 (–33.87)	–0.66 (–24.86)
00-07	2.94 (100)	2.02 (68.83)	1.48 (50.48)	–0.01 (–0.33)	0.34 (11.61)	0.00 (0.00)	–0.90 (–30.59)	–0.57 (–19.31)
Average 60-07	3.12 **(100)**	2.18 **(69.66)**	1.55 **(49.54)**	0.01 **(0.28)**	0.29 **(9.32)**	0.00 **(0.00)**	–0.90 **(–28.81)**	–0.60 **(–19.20)**
				Panel B: East Asia				
60-69	5.79 (100)	1.68 (29.06)	1.58 (27.22)	0.01 (0.12)	–0.17 (–2.88)	0.19 (3.33)	2.50 (43.15)	2.53 (43.72)
70-79	8.30 (100)	3.51 (42.28)	1.81 (21.85)	0.59 (7.15)	–0.30 (–3.65)	0.19 (2.24)	2.50 (30.14)	2.98 (35.88)
80-89	6.58 (100)	2.89 (43.88)	1.43 (21.68)	–0.16 (–2.50)	–0.25 (–3.78)	0.18 (2.71)	2.50 (38.00)	2.27 (34.43)
90-99	6.28 (100)	3.17 (50.44)	0.92 (14.68)	–0.11 (–1.71)	–0.38 (–5.97)	0.17 (2.73)	2.50 (39.83)	2.19 (34.88)
00-07	3.87 (100)	1.72 (44.60)	0.73 (18.94)	–0.93 (–23.97)	–0.33 (–8.55)	0.17 (4.32)	2.50 (64.67)	1.41 (36.46)
Average 60-07	6.28 **(100)**	2.62 **(41.66)**	1.32 **(20.95)**	–0.07 **(–1.08)**	–0.26 **(–4.19)**	0.18 **(2.86)**	2.50 **(39.80)**	2.35 **(37.38)**
				Panel C: Latin America				
60-69	1.54 (100)	2.12 (137.64)	–0.02 (–1.49)	–0.58 (–37.71)	0.02 (1.41)	–0.35 (–22.57)	0.35 (22.72)	–0.56 (–36.15)
70-79	1.91 (100)	3.13 (164)	–0.55 (–28.92)	–0.63 (–33.12)	0.03 (1.66)	–0.42 (–21.96)	0.35 (18.34)	–0.67 (–35.08)
80-89	1.52 (100)	1.29 (85.27)	0.99 (–65.47)	–0.64 (-42.42)	0.03 (1.90)	–0.51 (–33.26)	0.35 (23.05)	–0.77 (–50.73)
90-99	0.59 (100)	1.73 (294.87)	–0.11 (–18.09)	–0.81 (–137.75)	0.03 (5.08)	–0.61 (–103.80)	0.35 (59.69)	–1.04 (–176.78)
00-07	0.66 (100)	1.63 (246.96)	0.05 (7.04)	–0.71 (–107.81)	0.04 (5.35)	–0.69 (–104.48)	0.35 (52.94)	–1.02 (–15.40)
Average 60-07	1.28 **(100)**	1.99 **(154.85)**	0.09 **(7.20)**	–0.67 **(–52.25)**	0.03 **(2.15)**	–0.50 **(–39.23)**	0.35 **(27.28)**	–0.80 **(–62.05)**

Table B.4 (continued)

Year	$\hat{\dot{Y}} / \hat{Y}$	$(\alpha_1 + \alpha_2 V)\frac{\dot{K}}{K}$	$(\omega_1 + \omega_2 H)\frac{\dot{L}}{L}$	$\alpha_2 V \ln K \frac{\dot{V}}{V}$	$\omega_2 H \ln L \frac{\dot{H}}{H}$	$\frac{\dot{TE}}{TE}$	ξ	$\frac{\dot{TFP}}{TFP}$
Panel D: South Asia								
60-69	4.34 (100)	1.62 (37.41)	0.82 (18.86)	0.23 (5.22)	0.43 (10.02)	2.05 (47.15)	–0.81 (–18.67)	1.90 (43.72)
70-79	4.74 (100)	3.27 (68.86)	0.99 (20.80)	–0.35 (–7.39)	0.62 (12.97)	1.04 (21.83)	–0.81 (–17.07)	0.49 (10.34)
80-89	4.88 (100)	3.12 (63.88)	1.24 (25.49)	0.01 (0.20)	0.80 (16.29)	0.52 (10.74)	–0.81 (–16.59)	0.52 (10.63)
90-99	3.97 (100)	2.75 (69.24)	1.08 (27.18)	0.04 (1.09)	0.64 (16.22)	0.27 (6.68)	–0.81 (–20.42)	0.14 (3.57)
00-07	4.10 (100)	2.59 (63.19)	1.16 (28.26)	0.08 (1.93)	0.91 (22.24)	0.17 (4.12)	–0.81 (–19.74)	0.35 (8.55)
Average 60-07	4.39 **(100)**	2.68 **(61.08)**	1.05 **(23.94)**	–0.01 **(–0.20)**	0.63 **(14.37)**	0.85 **(19.24)**	–0.81 **(–18.43)**	0.66 **(14.98)**
Panel E: West								
60-69	4.27 (100)	2.93 (68.49)	0.27 (6.39)	0.16 (3.84)	0.10 (2.32)	0.71 (16.61)	0.10 (2.34)	1.07 (25.11)
70-79	3.88 (100)	2.78 (71.52)	0.32 (8.30)	–0.08 (–2.13)	0.13 (3.36)	0.64 (16.37)	0.10 (2.58)	0.78 (20.18)
80-89	2.47 (100)	1.57 (63.76)	0.39 (15.60)	–0.30 (–12.04)	0.14 (5.84)	0.56 (22.79)	0.10 (4.05)	0.51 (20.64)
90-99	2.85 (100)	1.79 (62.82)	0.36 (12.76)	–0.05 (–1.91)	0.15 (5.16)	0.50 (17.66)	0.10 (3.50)	0.70 (24.42)
00-07	3.40 (100)	2.19 (64.38)	0.38 (11.09)	0.11 (3.35)	0.15 (4.47)	0.47 (13.77)	0.10 (2.94)	0.83 (24.53)
Average 60-07	3.40 **(100)**	2.27 **(66.64)**	0.34 **(10.08)**	–0.04 **(–1.24)**	0.15 **(4.478**	0.58 **(17.11)**	0.10 **(2.94)**	0.79 **(23.28)**