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Productivity growth, human capital and distance to frontier in Sub-Saharan Africa

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Abstract

Using the Malmquist productivity index and panel data methods, we study the role of total human capital and its composition in the technological "catch –up" process and productivity growth via the channels of innovation and adoption of technology in a panel of 19 sub -Saharan African countries between 1960 and 2003. Our findings indicate different roles played by the composition of human capital and a follow-on consistent and significant contribution of total human capital to productivity growth. Primary and secondary school attainment (unskilled labour) contribute significantly to the adoption of technology(the main source of productivity growth in sub-Saharan Africa) whilst tertiary school attainment (skilled labour) plays a significant role in local innovation. Total human capital on the other hand, contribute more significantly to the adoption of technology and innovation. Technological "catch-up" remains a significant element in productivity growth in sub-Saharan Africa and economies with higher tertiary school attainment(skilled labour) and higher total human capital tend to contribute significantly to productivity growth through the channel of technological "catch-up". Our results rather point towards a circuitous depiction of the symbiotic characteristics of the composition of human capital in enhancing productivity growth in sub -Saharan Africa and hence efforts in scaling- up investments in human capital by governments, development partners etc should not be too concentrated on one composition of human capital.

Key words: Productivity growth · Human capital · Sub-Saharan Africa

JEL Classification: D24 · 047· 055

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Introduction

"Productivity isn't everything, but in the long run it is almost everything. A country's ability to improve its standard of living over time depends almost entirely on its ability to raise its output per worker".

Paul Krugman, The age of Diminishing Expectations (1994)

Recent empirical literature on economic growth investigating the proximate causes of the enormous differences in per capita income across countries usually indicate that these differences in incomes are largely a consequence of differences in total factor productivity (TFP) growth(Krugman, 1994;Klenow and Rodriguez-Clare, 1997; Hall and Jones, 1999; Easterly and Levine, 2001). Results from aggregative growth accounting studies (see Collins and Bosworth 2003; O'Connell and Ndulu, 2000, 2003) indicate a more prominent role to the total factor productivity residual in explaining Sub Saharan Africa's relatively slow growth over the last four decades than is usually acknowledged in the literature. The average TFP growth in a sample of 19 countries in sub-Saharan Africa from 1960 to 2000 was negative 0.1 percent with a peak of negative 1.4 percent from 1980 to 1990(Collins and Bosworth 2003). Devarajan *et. al*., (2003) suggest strongly, that TFP has played a major role in explaining this growth performance and therefore it is total factor productivity rather than the level of investment that has been the constraint to growth. Progress reports of the Millennium Development Goals (MDGs) and Poverty Reduction Strategy Papers (PRSPs) in most Sub-Saharan African countries indicate that a sustainable progress in productivity growth is required in order to achieve the targets set out in these programs.

There is a renewed emphasis on human capital or the educational attainment of the labour force as a significant factor to accelerate productivity and economic growth, even though there is no consensus among development economists on how human capital may help to promote growth. The earlier work by Nelson and Phelps (1966) argued that a more educated labour force would adopt new technologies faster, consequently closing the technological gap. This was given complementary theoretical support by the new endogenous growth theories (Romer, 1990a; Aghion and Howitt, 1992) who described the stock of human capital as the engine of growth through innovation. Romer (1990b) argues that the level of human capital may have an influence on the growth of productivity both directly and through the effect on the speed of adoption of the "catching- up" process. Stemming from these foundations, Benhabib and Spiegel (1994, 2005), Barro and Sala-i-Martin (1995) and Barro (1999) demonstrate that the stock of human capital not only enhances the ability of a country to develop its own technological innovation, but also increases its capacity to adopt the already existed knowledge elsewhere and thereby facilitates growth. On the other hand ,Lucas, (1988), and Mankiw *et al.,* (1992) argue that it is not the stock of human capital but rather the accumulation of human capital which is the main source of growth across countries. Surprisingly, the empirical evidence that human capital plays a significant role in economic growth is mixed[1]. A number of empirical studies find little or no correlation between economic growth and human capital while others have (see Mankiw *et al.,* 1992; Knowles and Owen, 1995; Caselli *et al*., 1996; Hoeffler, 2000; Pritchett 2001; Temple 2001; Trostel *et al*., 2002). The story is not different for studies on sub- Saharan Africa, O'Connell and Ndulu, (2000) reported that enrolment rates, educational attainment and human capital accumulation accordingly add relatively little to the explanation of cross country growth in sub Saharan Africa.

With regard to the importance of human capital for productivity growth, a number of empirical studies have investigated these linkages, mostly focusing on the developed OECD countries. The technological views of human capital (as discussed above by Nelson and Phelps, 1966 and the new endogenous growth theorists) have received more empirical support in the work of Benhabib and Spiegel (1994, 2005), Barro and Sala-i-Martin (1995) and Barro (1998), all of whom showed that both the initial schooling level and its interaction with a measure of the technology gap with the frontier were positively associated with subsequent growth. Benhabib and Spiegel (1994) using cross-country data from 78 countries over the period of 1965 to 1985 and an alternative endogenous model where productivity growth is the result of a combination of innovation and adoption of technology observed that the growth rate of productivity depends on a nation's human capital stock level when they accounted for differences in initial technology levels across countries. Benhabib and Spiegel (1994) concluded that the role of human capital is indeed one of facilitating adoption of technology from abroad and creation of appropriate domestic technologies rather than entering on its own as a factor of production. They also suggested that technological ""catch-up"" remains a significant element in growth and that country with higher education tend to close the technology gap faster than others.

Using Benhabib and Spiegel (1994) model, for a sample of 78 countries over the period of 1965 to 1985 Krueger and Lindhal (2001) argue that education is statistically significant and positively associated with growth only for the countries with low level of human capital. Benhabib and Spiegel (2005) for a second time applied cross-sectional data from 84 countries over the period of 1960 to 1995 and generalize the Nelson and Phelps (1966) "catch-up" model of technology diffusion facilitated by levels of human capital. Their results lend some support to the notion that human capital contributes significantly to productivity growth through the channel of technological "catch-up". The direct effect of human capital on productivity growth becomes less robust in their estimation.

Following the same specification for productivity growth by Benhabib and Spiegel (1994), Vandenbussche *et al*.,(2006) investigate why the relationship between education and growth is insignificant for richer countries in the work by Krueger and

[1]Some economists (Temple,1998; Krueger and Lindhal, 2001; and Serrano, 2003) have attributed these mixed results to significant measurement error and the endogeneity problem in educational attainment (Bils and Klenow, 2000).

Lindhal (2001). To solve this puzzle posed by Krueger and Lindhal (2001), they focus attention on an economy's distance to the technological frontier and on the composition of its human capital. Assuming that innovation requires highly educated skilled labor, they argue that the countries close to the technological frontier should engage in innovation and therefore, the growth enhancing effect of the skilled labor increases with the proximity of the technological frontier. On the other hand, the growth enhancing effect of unskilled labor decreases with the proximity to technological frontier. Using a panel data of 19 OECD countries. they show that the growth enhancing properties of human capital to productivity growth depend on both its composition and the distance to the technological frontier. Their results indicate that the growth-enhancing margin in OECD countries is that of skilled human capital (tertiary educational attainment) rather than that of total human capital. In addition skilled human capital has a higher growth enhancing effect closer to the technological frontier under the assumption that innovation is a relatively more skill-intensive activity than adoption of technology.

Recent studies, all following the work by Vandenbussche *et al.* (2006) , have attempted to examine the contribution of human capital in a larger panel of countries (including low income countries) through the channel of innovation as well as imitation. Islam(2009) used a panel of 87 (including 22 low income countries) sample countries over the period of 1970 to 2004. His results demonstrate that the growth enhancing effect of skilled human capital (tertiary school attainment) increases with the proximity to the technology frontier only for high and medium income countries whilst unskilled human capital (primary and secondary school attainment) is contributing more for low income countries as they move closer to the technology frontier. The conclusions of Azomahou *et. al.,*(2009) indicate that tertiary education is a key asset in knowledge based economies and therefore countries which are near the technology frontier have to invest in higher education while those far away from the frontier make their technology level growing up by investing in primary and secondary education. These studies sort to support Vandenbussche *et al.*,(2006) on the positive contribution of tertiary education in the OECD countries and provide an alternative positive role for primary and secondary school attainment for low income countries.

The empirical literature on the technological view of human capital (discussed above) employ an extension of the Nelson and Phelps (1966) model in an endogenous framework based on the production function to study the role of total human capital and the composition of human capital in innovation and the adoption of technology across countries[2]. We rather investigate this same subject matter(total human capital and composition) for a panel of 19 countries in sub Saharan Africa, where studies on these subject is lacking using frontier and panel data methods. Unlike the use of the

[2] There is no distinction between technical progress and changes in technical efficiency with which a known technology is applied to production (embodied technological change). This embodied technology forms the very essence of the endogenous growth model.

production function in these studies above, which assume that all the units of production are efficient, our use of the frontier methods consider the possible existence of inefficient behavior and rather estimate a production frontier that represents the maximum technically attainable level of production. More importantly, our use of the Malmquist productivity index enable us to derive productivity growth and its two channels of technical progress (innovation) and technical efficiency (adoption of technology) as well as the distance of each country in the sample to the world technology frontier. This affords us the opportunity to clearly look at human capital and composition effects on innovation , technological adoption, the technological catch –up process and the overall TFP. We use different panel data methods to study the effect of total stock of human capital, the composition of human capital and distance to the technological frontier on productivity growth via innovation and adoption of technology. We also study the role of total human capital and composition of human capital in the technological ""catch-up"" process in sub- Saharan Africa.

The paper is organized as follows. The second section offers a review of the methodology and the third section describes the data used for the study. The fourth section analyses our estimation results and finally the main conclusions of the paper are presented in section four.

2. Methodology

The study make use of the output based Malmquist productivity index and the non parametric frontier method , data envelopment analysis, DEA to compute TFP growth and its two components, technical progress (innovation) and technical efficiency(adoption of technology) as well as the distances of each country to the technological frontier for the 19 countries in our sample. Panel data methods are used to investigate the relationship between aggregate stock of human capital, composition of human capital, the distance to the technological frontier and TFP growth (and components). The effect of total human capital and composition on the technological ""catch-up"" process (Nelson and Phelps, 1966 catch –up hypothesis) in sub Saharan Africa is also examined. Following Vandenbussche *et al.*,(2006), we estimate total human capital effects on productivity and components holding the composition effects constant and estimate composition effects holding the level of total human capital constant. In an attempt to deal with problems such as endogeneity, measurement errors and omitted variable biases in estimating and interpreting our panel data regressions(see Temple 1999, pg. 125-131), we draw on three alternative panel estimators, pooled Ordinary Least squares (OLS), instrumental variables (IV) and system Generalized Method of Moments (GMM)[3].

[3] System GMM(see Blundell and Bond, 1998) jointly estimates the equation in levels and in first difference, imposing the restriction that the coefficients in the level and differenced equation are equal.

2.1 The Malmquist Productivity Index Approach

This section describes the output based Malmquist productivity index and the non parametric frontier method, data envelopment analysis, DEA used in this study to measure productivity. The Malmquist productivity index (Malmquist 1953) allows changes in productivity to be broken down into changes in efficiency and technical change. The DEA approach does not require any functional specification for the relationship between inputs and outputs or for the inefficiency error term. Using it means escaping various specifications and estimation problems. On the other hand, the main disadvantage of the DEA is its deterministic nature and the resulting inability to distinguish between technical inefficiency and statistical noise. The alternative parametric Stochastic Frontier Approach, SFA is able to handle these outliers and hypothesis can be tested in the econometric way. However some of the disturbing drawbacks of the SFA is the assumption of a distributional form of the error term as well as a functional form of the production function A detailed exposition of Malmquist productivity index and the non parametric DEA approach is provided in Färe *et. al.,* (1994).

The Malmquist index is defined in terms of output distance functions. These functions measure the ray distance between a given output vector and maximal potential output. This maximal output belongs to the boundary of the reference or frontier technology. As shown in Färe, Grosskopf and Margaritis (2006) and essentially using their notations, we start by explaining how the frontier is constructed from data in our case.

At each time period $t = 1, \ldots, 43,$ there are $k = 1, \ldots, 41$ countries[4] that use two inputs, physical capital stock and labour, $\mathbf{x}^{k,t}=(X_{1k}, X_{2k})$ to produce a single output, real GDP, $\mathbf{y}^{k,t}=(Y_k)$.From these observations an overall (world) production technology is constructed for each time period. Rather than specifying and estimating a specific production function we choose to construct the technologies non-parametrically using activity analysis. This technique is also known as Data Envelopment Analysis (DEA) (see Charnes *et. al.,* 1978).[5]

[4] 22 OECD countries are added to the sample of 19 SSA countries in order to determine a (world) technology.

[5] This technique does not impose a specific production function on each country with identical parameters (e.g., fixed input elasticties).Technology is much more general than a typical parametric production function. This approach merely takes the observed data, constructs the frontier from these observed data, and uses that frontier as a benchmark. Assumptions about competitive behaviour or other assumptions about market structure are not require, rather minimal regularity conditions (disposability of inputs and outputs, for example) are imposed. Technical change is define as shifts in the frontier between t and $t + 1$.I t must be noted that data measurement problems will affect our measure of technical change, as they would for any of the techniques used to measure TFP or technical change.

For a given period t, the constant returns to scale (CRS) frontier technology is

$$S^{t}_{CRS} = \{\left(x^{t}, y^{t}\right) : \sum_{k=1}^{K} z_{k} y^{t}_{k} \geq \theta y^{t+1},$$

$$\sum_{k=1}^{K} z_{k} y^{t}_{nk} \leq x^{t+1}_{nk},$$

n = 1, 2, zk ≥ 0, k = 1, . . . ,41} (1)

In this formulation output levels may be less than or equal to linear combinations of observed output, that is, output is freely disposable. Input levels may be greater or equal to linear combinations of observed input, that is, producers may freely dispose of inputs as well. The intensity variables, *zk,* indicate at what intensity a particular activity (or observation) may be employed in production. They are only required to be non-negative, thus they form the convex cone of the data. The convexity implies that convex combinations of observed inputs and outputs are hypothetically feasible. The technology being a cone is equivalent to constant returns to scale. The upper boundary of this set represents the best practice frontier.

Relative to a frontier technology S^t , one may define the corresponding output distance function for country k as

$$D_0^t\left(x^{k^t,t}, y^{k^t,t}\right) = \min\left\{\theta : \left(x^{k^t,t}, \frac{y^{k^t,t}}{\theta}\right) \epsilon\, S^t\right\}$$

$$= \left[\max\left\{\theta : \left(x^{k^t,t}, \theta y^{k^t,t}\right) \epsilon\, S^t\right\}\right]^{-1}$$

$$= \left[F_0^t\left(x^{k^t,t}, y^{k^t,t}\right)\right]^{-1} \quad (2)$$

(see Shephard 1970; Färe 1988 for details). In (2) $F_0^t(.)$ denotes the Farrell (1957) output-oriented measure of technical efficiency. Thus (2) shows that the distance function and the Farrell technical efficiency measure are reciprocals. This fact is important, since we decompose our productivity index into two components: one measuring efficiency change and another measuring technical change. This index has become known as the Malmquist index. It was introduced as a theoretical index by Caves et al. (1982) who named it the (output based) Malmquist productivity index after Sten Malmquist who had earlier shown how to construct quantity indexes as ratios of distance functions (see Malmquist 1953).

Following Färe et al. (1989) the Malmquist productivity change index (M) is defined as

$$M_0\left(k^t, t, t+1\right) = \left[\frac{D_0^t\left(x^{k^t,t+1}, y^{k^t,t+1}\right)}{D_0^t\left(x^{k^t,t}, y^{k^t,t}\right)} \frac{D_0^{t+1}\left(x^{k^t,t+1}, y^{k^t,t+1}\right)}{D_0^{t+1}\left(x^{k^t,t}, y^{k^t,t}\right)}\right]^{1/2} \quad (3)$$

An important feature of the Färe et al. (1989) version of the Malmquist index (3) is that it can be decomposed into two independent components, namely

$$\text{Efficiency Change =ECH=} \quad \frac{D_0^t\left(x^{k^t,t+1}, y^{k^t,t+1}\right)}{D_0^t\left(x^{k^t,t}, y^{k^t,t}\right)} \qquad (4)$$

and

$$\text{Technological change = TCH=} \left[\frac{D_0^t\left(x^{k^t,t+1}, y^{k^t,t+1}\right) D_0^t\left(x^{k^t,t}, y^{k^t,t}\right)}{D_0^{t+1}\left(x^{k^t,t+1}, y^{k^t,t+1}\right) D_0^{t+1}\left(x^{k^t,t}, y^{k^t,t}\right)}\right]^{1/2} \qquad (5)$$

Thus (3) can be written as

$$M_0\,(k^t \;, t\,, t+1) \;\; = \text{MALM} = \text{ECH} \times \text{TCH} \qquad (6)$$

and for each country k^t = 1, . . . , 41, time paths of productivity, efficiency and technical change can be calculated.

Fig. 1 is used to illustrate expression (6), the productivity index and its components. For the diagram, we assume that one input is used to produce one output, and that the reference technologies satisfy constant returns to scale. There are two observations, (x^t, y^t) and (x^{t+1}, y^{t+1}), respectively. Note that (x^{t+1}, y^{t+1}) is not feasible at period t. However, (x^t, y^t) ϵ S_{CRS}^{t+1} indicates that technical progress has occurred.

The indices can be illustrated as distances on the output axis. The change in efficiency is obtained as the ratio of the distance of the period t +1 observation relative to its frontier to the period t observation from its frontier as

$$\text{ECH=} \frac{0d}{0f}\frac{0b}{0a}$$

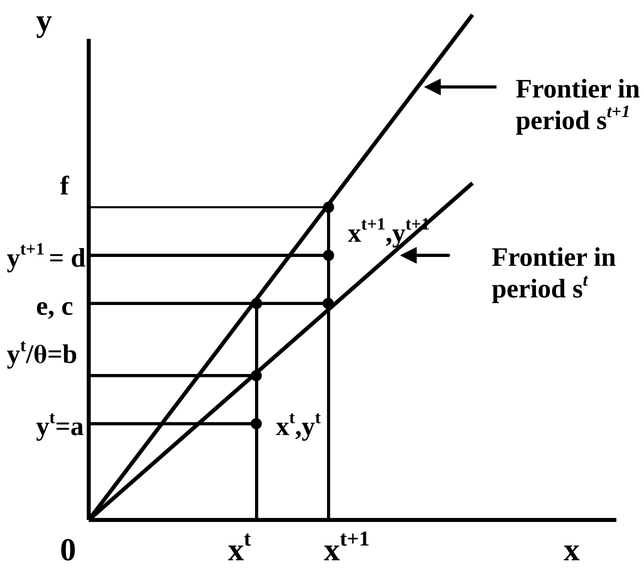
The technical change part equals the geometric average of the shift in the frontier in the output direction from period t to period t +1 evaluated at points (x^{t+1}, y^{t+1}) and (x^t, y^t), respectively,

$$\text{TCH} = \left(\frac{0f}{0e}\frac{0c}{0b}\right)^{1/2}$$

and hence the productivity change is

$$\text{MALM} = \frac{0d}{0a}\left(\frac{0b}{0e}\frac{0c}{0f}\right)^{1/2}$$

Figure 1: The Malmquist Productivity index



The productivity index and its components are all constructed from distance functions. We note that there are two mixed period distance functions, namely $D^{t+1}(x^t, y^t)$ and $D^t(x^{t+1}, y^{t+1})$, that are involved in the computation of the Malmquist productivity index.

Therefore, we need to compute a total of four distance functions; $D^t(x^{t+1}, y^{t+1})$, $D^t(x^t, y^t)$, $D^{t+1}(x^{t+1}, y^{t+1})$ and $D^{t+1}(x^t, y^t)$ in order to estimate the productivity of country k^{t} between t and $t+1$. For a given country k^{t} we can calculate the reciprocal of the distance function $D^t(x^{t+1}, y^{t+1})$ as the solution to the following linear programming problem:

$$\left\lfloor \left| D_0^t\,(x^{k^{\text{t}},t+1}, y^{k^{\text{t}},t+1} \right| CRS) \right\rfloor^{-1} = \max\theta \ \text{ s. t.}$$

$$\sum_{k=1}^{K} z_k y_k^t \geq \theta y^{t+1},$$

$$\sum_{k=1}^{K} z_k y_{nk}^t \leq x_{nk}^{t+1}, \quad \text{n} = 1,2\ ;\ z_k \geq 0,\ k = 1\ldots\ldots.41. \qquad (7)$$

where the input and output data are from period $t+1$ while the technology is constructed from data at period t, that is, the linear programming problem is a mixed period problem. The three remaining distance functions required by (3) can be similarly computed.

We calculate the Malmquist index and its components under the CRS technology. Fluctuations in productivity may be due to variation in capacity utilisation and differences in the structure of each country which will be reflected in changes in the efficiency component. This follows from the fact that observations are compared to the best practice frontier.

Improvements in productivity yield Malmquist index values greater than unity. Deterioration in performance over time is associated with a Malmquist index less than unity. The same interpretation applies to the values taken by the components of the overall TFP index. Improvements in the efficiency component yield index values greater than one and are considered to be evidence of catching up (to the frontier). Values of the technical change component greater than one are considered to be evidence of technical progress. While the product of the efficiency and technical change components must, by definition, equal the Malmquist index, those components may be moving in opposite directions.

The novelty of this approach discussed above is that it allows to decompose productivity growth into two mutually exclusive and exhaustive components. The product of these two components yields a frontier version of the Malmquist productivity Index. These components lend themselves in a natural way to the identification of catching up and the identification of innovation respectively. The efficiency change component is also expected to capture diffusion of technology and reflect the variations in capacity utilization and differences in the structure of the economy whether regulated or competitive in economic applications which employs aggregate macro data (Färe *et. al.,* 1994).

2.2 Empirical specifications

We generate an panel dataset of 5 year averages and consider the following empirical specification:

$$tfp_{j,t} = \alpha tfp_{j,t-1} + \beta hc_{j,t} + \gamma df_{j,t} + \rho hc_{j,t} \times df_{j,t} + \phi Z_{j,t} + \lambda_t + \eta_j + \varepsilon_{j,t} \quad (8)$$

$$tfp_{j,t} = \alpha tfp_{j,t-1} + \beta_1 prim_{j,t} + \beta_2 sec_{j,t} + \beta_3 tert_{j,t} + \gamma df_{j,t} + \rho_1 prim_{j,t} \times df_{j,t} + \rho_2 sec_{j,t} \times df_{j,t} + \rho_3 tert_{j,t} \times df_{j,t} + \lambda_t + \eta_j + \varepsilon_{j,t} \quad (9)$$

$$tech_{j,t} = \alpha tech_{j,t-1} + \beta hc_{j,t} + \gamma df_{j,t} + \phi Z_{j,t} + \lambda_t + \eta_j + \varepsilon_{j,t} \quad (10)$$

$$tech_{j,t} = \alpha tech_{j,t-1} + \beta_1 prim_{j,t} + \beta_2 sec_{j,t} + \beta_3 tert_{j,t} + \gamma df_{j,t} + \lambda_t + \eta_j + \varepsilon_{j,t} \quad (11)$$

$$eff_{j,t} = \alpha eff_{j,t-1} + \beta hc_{j,t} + \gamma df_{j,t} + \rho hc_{j,t} \times df_{j,t} + \phi Z_{j,t} + \lambda_t + \eta_j + \varepsilon_{j,t} \quad (12)$$

$$eff_{j,t} = \alpha eff_{j,t-1} + \beta_1 prim_{j,t} + \beta_2 sec_{j,t} + \beta_3 tert_{j,t} + \gamma df_{j,t} + \rho_1 prim_{j,t} \times df_{j,t} + \rho_2 sec_{j,t} \times df_{j,t} + \rho_3 tert_{j,t} + \lambda_t + \eta_j + \varepsilon_{j,t} \quad (13)$$

$$j = 1,2, \dots \dots 19, \quad t = 1,2, \dots 8.$$

Where $tfp_{j,t}$, $tech_{j,t}$ and $eff_{j,t}$ are TFP growth, technical progress and technical efficiency in country j at period t. $hc_{j,t,}$ $prim_{j,t}$, $sec_{j,t}$ and $tert_{j,t}$ are the log of total human capital stock, primary, secondary and tertiary school attainment respectively in country j at period t. $df_{j,t}$ represent the log of the distance to the world technology frontier in country j at period t. The interaction terms $hc_{j,t} \times df_{j,t}$, $prim_{j,t} \times df_{j,t}$, $sec_{j,t} \times df_{j,t}$ and $tert_{j,t} \times df_{j,t}$ measures the growth enhancing effect of total human capital, primary, secondary and tertiary education on productivity growth(technical efficiency) with proximity to the technological frontier . $Z_{j,t}$ is a set of control variables, population, government consumption (as a percentage of GDP), inflation, M2 (percentage of GDP), openness and polity. $\lambda_{t,}$ a constant, $\eta_{j,}$a time specific effect and $\varepsilon_{j,t,}$ the error term. The equations are estimated using pooled Ordinary Least squares (OLS), instrumental variables and system Generalized Method of Moments (GMM).The observation for each country is averaged over a 5 year period. We treat $hc_{j,t,}prim_{j,t}$ $sec_{j,t}$, $tert_{j,t}$ and $df_{j,t}$ and the interaction term as endogenous. Our instruments are the log of total human capital, primary, secondary and tertiary school attainment lagged two periods ($hc_{j,t-2,}prim_{j,t-2,}sec_{j,t-2,}$ and $tert_{j,t-2,}$), log of distance to the frontier lagged two periods ($df_{j,t-2}$) and the interaction of these instruments together with time dummies to ensure that our results are not driven by time specific effects. The validity of the IV and GMM Instruments are tested using the Hansen J statistic and the Sargan or Hansen test for over-identifying restrictions respectively.

2.3 Data

The sample used for the estimation of the world technological frontier and computing the malmquist productivity index consists of 41 countries over the period 1960 – 2003. The observations for each country are annual and the variables are: (1) real Gross Domestic Product in (2000) international dollars derived from the World Development Indicators and the Heston, Summers and Aten, (2006) database (Penn World Table 6.2) (2) total labour force is measured by the economic active population, that is the population aged between 15 and 64 years and sourced from the WDI (3) capital stock is calculated by applying a perpetual inventory method using initial 1950 capital stocks derived from a World Bank study by Nehru and Dhareshwar (1993) with a depreciation rate of 0.05. Investment data are taken from a World Development Indicators.

Total human capital and the composition is the average educational attainment of total population aged 15 years and over and is calculated as an average of series from Barro and Lee (2000) and Cohen and Soto(2001) where both are available or by available series if only one is available. This was obtained from Collins and Bosworth (2003).[6]

[6] Collins and Bosworth(2003) constructed a human capital index based on the simple annual averages of Barro - Lee (2000) and Cohen - Soto(2001) estimates of years of schooling. I am grateful to Susan Collins for access to the data.

Productivity growth, technical progress and technical efficiency for the 19 sub Saharan African countries under study are obtained from our calculated Malmquist productivity indexes[7](see appendix, table 1). The distance of each country to the world technology frontier is estimated as the reciprocal of the calculated technical efficiency of each country in the sample. Our set of control variables- population, government consumption (as a percentage of GDP), inflation and M2 (percentage of GDP) are taken from the WDI (2009) [8]. Openness, measured as the ratio of exports plus imports to GDP (in constant prices) is derived from Heston, Summers and Aten, (2006) database (Penn World Table 6.2). Our measure for the quality of institutions or democracy is polity sourced from Marshall and Jaggers, (2009, Polity IV Project). [9]

3. Estimation results

The models specified in section 2.2 are estimated using pooled OLS, instrumental variables and system GMM and presented in tables 2-10 at the appendix. Total human capital stock has a positive and significant effect on productivity and its components of technical progress and technical efficiency respectively. The interaction between total human capital and the distance to the world technological frontier is also positive and significant, see columns [2] and [3] of table 4, demonstrating the positive growth enhancing effect of total human capital to the technological "catch- up" process and productivity growth when economies are closer to the world technological frontier. This is an illustration of the ""catch-up"" hypothesis by Nelson and Phelps (1966), albeit using a different approach. These results are consistent and robust (with controls), see columns [2] and [3] of table 4. The composition of human capital on the other hand has different results in their contribution to productivity growth(see tables 5-7). Primary and secondary school attainment have a negative (not significant) effect on technical progress and productivity growth while tertiary school attainment has a positive effect. Primary and secondary school attainment rather have a positive and significant effect on technological adoption, the main source of productivity growth in sub-Saharan Africa (see appendix, table 1) and tertiary school has a negative relationship. However, the growth enhancing effect of secondary school attainment (to technological "catch-up") decreases with closeness to the frontier whilst tertiary school attainment responds positively and turn out to be growth enhancing.

Using tertiary school attainment as a proxy for skilled labour and school attainment from primary to secondary as unskilled labour, our estimates (see tables 8-10)also show that unskilled labour has a negative effect on productivity and technical progress while skilled labour has a positive relationship. Unskilled labour has a significant

[7] All DEA computations were performed using the computer program DEAP Version 2.1 (Coelli 1996).
[8] M2 is money and quasi money and it comprise the sum of currency outside banks, demand deposits other than those of the central government, and the time, savings, and foreign currency deposits of resident sectors other than the central government.
[9] The POLITY score is computed by subtracting the AUTOC score from the DEMOC score; the resulting unified polity scale ranges from +10 (strongly democratic) to -10 (strongly autocratic).

positive contribution to technological adoption and skilled labour has a negative role. The growth enhancing effects of unskilled labour decreases as countries move closer to the frontier but the growth enhancing impact of skilled labour is positive playing an important role in technological "catch-up".

The effect of distance to the world technological frontier on productivity growth is negative and strongly significant implying a TFP convergence in our sample for Sub Saharan Africa not mediated by human capital. Its effect on technical efficiency is also negative and very significant indicating proximity to the world technological frontier increases the adoption of technology, a "catching up" to the world technological frontier independent of human capital. However the effect of distance to the world technological frontier on technical progress is positive and significant signalling a divergence in innovation when distance to the world technological frontier decreases. The effects of distance to the world technological frontier are also consistent and robust.

4. **Conclusion and policy recommendations**

Using the malmquist productivity index and panel data methods, we study the role of total human capital as well as the composition of human capital in productivity growth via the channels of technical progress and technical efficiency in a panel of 19 sub Saharan countries between 1960 and 2003. Our results indicate the different roles played by the components of human capital and the resulting superior and positive contribution of total human capital to productivity growth. Primary and secondary school attainment (unskilled labour) plays significant roles in the adoption of technology, the main source of productivity growth in sub-Saharan Africa but its growth enhancing effects decreases with proximity to the frontier. Tertiary school attainment has significant roles in innovation and productivity growth and also plays an important role in technological "catch- up" process as its impacts is increasing and growth enhancing with proximity to the frontier. Total human capital on the other hand, plays a more significant role in productivity and all the components. It has a stronger growth enhancing and positive effect in the technological "catch –up" process as well.

Although our findings support the main assertions of Benhabib and Spiegel (1994, 2005) and Krueger and Lindhal (2001) regarding the contribution of total human capital, it says the opposite with regards to the contributions of the composition of human capital to productivity growth and the technological catch-up process reported by Islam (2009) and Azomahou *et. al.,*(2009) for low income countries. Thus, a note of caution not to oversimplify the findings by Vandenbussche *et al*.,(2006) for low income countries. There is rather a circuitous depiction of the symbiotic characteristics of the composition of human capital in enhancing productivity growth in sub Saharan Africa when we consider productivity growth charily through the channels of innovation and technological adoption. As policymakers, development partners, Non Governmental Organisations etc scale up investments in human capital in sub-Saharan Africa, it should not be too concentrated on one composition at the detriment of the others. In some way, balanced investment in human capital (based on levels of the compositions of human capital in each country) would help countries to achieve productivity growth.

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Appendix

Table 1: Mean country Malmquist productivity index and decomposition, 1960- 2003

Country	MALM TFP	Technical efficiency	Technical progress
Cote d' Ivoire	0.993	1.016	0.978
Cameroon	0.984	1.01	0.975
Ethiopia	0.979	1	0.979
Ghana	0.984	1.004	0.98
Kenya	1.003	1.025	0.979
Madagascar	0.982	1	0.982
Mali	0.998	1.019	0.98
Mozambique	0.971	1.01	0.961
Mauritius	1.007	1.037	0.971
Malawi	0.967	0.99	0.977
Nigeria	0.961	0.978	0.982
Rwanda	0.974	0.999	0.975
Senegal	1	1.02	0.98
Sierra Leone	0.976	1.009	0.967
Uganda	0.905	0.999	0.906
Tanzania	0.994	1.014	0.98
South Africa	0.976	1.019	0.958
Zambia	0.904	1.015	0.89
Zimbabwe	0.995	1.015	0.98
Overall Mean	**0.976**	**1.009**	**0.967**

Source: Authors' calculations

Note: All numbers in the table are index numbers. Subtracting 1 from the number reported in the table gives average increases or decreases per annum for the relevant time period and relevant performance measure.

Table 2: Total human capital, distance to frontier and productivity growth, 1960-2003

	Pooled OLS			IV			SYS- GMM		
TFP	(1)	(2)	(3) With Controls	(1)	(2)	(3) With Controls	(1)	(2)	(3) With Controls
Human capital	0.199***	0.166**	0.128*	0.155*	0.189*	0.180*	0.389**	0.242*	0.147*
	(0.0735)	(0.0757)	(0.0741)	(0.0895)	(0.102)	(0.0955)	(0.154)	(0.140)	(0.0824)
Distance to frontier	-0.302***	-0.337***	-0.309***	-0.421**	-0.551***	-0.541***	-0.274*	-0.775**	-0.456***
	(0.113)	(0.106)	(0.0868)	(0.173)	(0.211)	(0.208)	(0.144)	(0.321)	(0.126)
Human capital * Distance to frontier		3.493846***	2.034057		3.208*	3.021*		5.151*	2.034
		(1.249861)	(1.36001)		(1.806)	(1.808)		(2.797)	(1.470)
Log of population		0.00210	0.00952		0.00696	0.0110		0.0140	0.0101
		(0.00967)	(0.0113)		(0.0102)	(0.0119)		(0.0164)	(0.0110)
Openness		0.0164**	0.0210**		0.0263**	0.0283***		0.0162	0.0219***
		(0.00811)	(0.00889)		(0.0110)	(0.0109)		(0.0152)	(0.00777)
Govt consumption (% of GDP)		-0.145***	-0.177***		-0.177***	-0.183***		-0.231**	-0.178***
		(0.0545)	(0.0582)		(0.0589)	(0.0674)		(0.110)	(0.0572)
Inflation			-0.144***		-0.155***	-0.148***		-0.191***	-0.150***
			(0.0369)		(0.0345)	(0.0363)		(0.0351)	(0.0246)
m2 (% of GDP)			0.00263			-0.00162			0.00230
			(0.00343)			(0.00286)			(0.00444)
Polity			0.00105*			0.000826			0.000930
			(0.000627)			(0.000671)			(0.000649)
Constant	0.991***	0.940***	0.943***	0.955***	0.900***	0.891***	0.938***	0.944***	0.936***
	(0.00570)	(0.0349)	(0.0373)	(0.00983)	(0.0481)	(0.0479)	(0.0155)	(0.0715)	(0.0376)
Observations	152	152	124	152	152	124	152	152	124
R-squared	0.453	0.498	0.546	0.151	0.515	0.524			
AR(1)							0.012	0.001	0.002
AR(2)							0.503	0.147	0.244
Sargan/ Hansen *p –value*				0.3546	0.1865	0.2126	0.153	0.110	0.116

Note: t statistics based on standard errors robust to heteroskedasticity and autocorrelation are reported in parenthesis. Significance at 1%, 5% and 10% level is indicated by ***, ** and * respectively. All regressions include period dummy variables.

Table 3: Total human capital, distance to frontier and technical progress (innovation), 1960-2003

	Pooled OLS			IV			SYS- GMM		
TECH	(1)	(2)	(3) With Controls	(1)	(2)	(3) With Controls	(1)	(2)	(3) With Controls
Human capital	0.201***	0.200**	0.152*	0.164*	0.180*	0.173*	0.361***	0.200***	0.152*
	(0.0753)	(0.0812)	(0.0787)	(0.0931)	(0.103)	(0.0959)	(0.116)	(0.0766)	(0.0825)
Distance to frontier	0.573***	0.341***	0.450***	0.435**	0.326*	0.338*	0.778***	0.341***	0.450***
	(0.106)	(0.121)	(0.128)	(0.173)	(0.188)	(0.186)	(0.128)	(0.113)	(0.126)
Log of population		0.00274	0.00811		0.00715	0.00979		0.00274	0.00811
		(0.00891)	(0.0109)		(0.0103)	(0.0120)		(0.00946)	(0.0110)
Openness		0.0182**	0.0228**		0.0284**	0.0300***		0.0182***	0.0228***
		(0.00819)	(0.00916)		(0.0113)	(0.0111)		(0.00657)	(0.00777)
Govt consumption (% of GDP)		-0.134**	-0.161***		-0.171***	-0.173**		-0.134***	-0.161***
		(0.0524)	(0.0589)		(0.0606)	(0.0692)		(0.0513)	(0.0573)
Inflation			-0.152***		-0.157***	-0.151***		-0.160***	-0.152***
			(0.0383)		(0.0356)	(0.0379)		(0.0230)	(0.0246)
m2 (% of GDP)			0.00282			-0.00115			0.00282
			(0.00381)			(0.00316)			(0.00444)
Polity			0.000794			0.000677			0.000794
			(0.000625)			(0.000684)			(0.000650)
Constant	0.987***	0.927***	0.928***	0.949***	0.889***	0.883***	0.998***	0.927***	0.928***
	(0.00589)	(0.0362)	(0.0391)	(0.0102)	(0.0494)	(0.0487)	(0.00732)	(0.0320)	(0.0376)
Observations	152	152	124	152	152	124	152	152	124
R-squared	0.420	0.517	0.567	0.196	0.562	0.571			
AR(1)							0.001	0.001	0.003
AR(2)							0.692	0.367	0.692
Sargan/ Hansen *p –value*				0.3994	0.2294	0.2300	0.159	0.123	0.159

Table 4: Total human capital, distance to frontier and technical efficiency (adoption of technology), 1960-2003

	Pooled OLS			IV			SYS GMM		
EFFECH	(1)	(2)	(3) With Controls	(1)	(2)	(3) With Controls	(1)	(2)	(3) With Controls
Human capital	0.0300**	0.0495***	0.0426**	0.0251*	0.0421**	0.0351*	0.0487*	0.0665***	0.0426*
	(0.0142)	(0.0186)	(0.0212)	(0.0129)	(0.0190)	(0.0204)	(0.0292)	(0.0248)	(0.0240)
Distance to frontier	-1.022***	-1.072***	-1.120***	-1.019***	-1.104***	-1.135***	-1.023***	-1.155***	-1.120***
	(0.0515)	(0.0229)	(0.0284)	(0.0604)	(0.0304)	(0.0314)	(0.0218)	(0.0532)	(0.0321)
Human capital * Distance to frontier		0.358	0.736**		0.665**	0.865**		1.267**	0.736**
		(0.274)	(0.326)		(0.328)	(0.345)		(0.516)	(0.369)
Log of population		-0.000827	-0.0000384		-0.000930	-0.0000805		-0.00282	-0.0000384
		(0.00188)	(0.00222)		(0.00199)	(0.00224)		(0.00315)	(0.00251)
Openness		-0.00212*	-0.00172		-0.000911	-0.00158		-0.00315	-0.00172
		(0.00124)	(0.00161)		(0.00153)	(0.00175)		(0.00258)	(0.00182)
Govt consumption (% of GDP)		-0.00904	-0.000961**		-0.000199	-0.00129***		-0.000326	-0.000961*
		(0.00988)	(0.000449)		(0.000362)	(0.000485)		(0.000738)	(0.000509)
Inflation			0.00574			0.00500			0.00574
			(0.00512)			(0.00482)			(0.00580)
m2 (% of GDP)			-0.00112			-0.000723			-0.00112
			(0.000929)			(0.000859)			(0.00105)
Polity			0.0000333			0.000133			0.0000333
			(0.000138)			(0.000139)			(0.000157)
Constant	1.004***	1.013***	1.010***	1.005***	1.008***	1.016***	1.004***	1.018***	1.010***
	(0.00167)	(0.00587)	(0.00811)	(0.00160)	(0.00685)	(0.00881)	(0.00218)	(0.0117)	(0.00918)
Observations	152	152	124	152	152	124	152	152	124
R-squared	0.950	0.981	0.984	0.945	0.983	0.985			
AR(1)							0.000	0.000	0.001
AR(2)							0.595	0.254	0.597
Sargan/ Hansen *p –value*				0.3173	0.2306	0.1835	0.110	0.468	0.731

Table 5: Composition of human capital, distance to frontier and productivity growth, 1960-2003

	Pooled OLS		IV			SYS- GMM	
TFP	(1)	(2)	(1)	(2)		(1)	(2)
Primary	-0.0137	-0.0257	-0.0170	-0.0216		0.0249	-0.0283
	(0.0394)	(0.0446)	(0.0509)	(0.0523)		(0.130)	(0.0769)
Secondary	-0.0547	-0.0371	-0.133	-0.146		-0.0381	0.00866
	(0.0709)	(0.0713)	(0.105)	(0.108)		(0.161)	(0.104)
Tertiary	0.488	0.418	0.961*	1.056*		0.00790	0.00463
	(0.418)	(0.422)	(0.599)	(0.625)		(0.672)	(0.413)
Distance to the frontier	-0.498***	-0.312	-0.447**	-0.177		-0.395***	-0.170
	(0.182)	(0.265)	(0.185)	(0.304)		(0.105)	(0.275)
Primary* Distance to the frontier		-0.869		-0.755			-2.269
		(0.969)		(1.260)			(1.554)
Secondary * Distance to the frontier		0.841		-0.165			1.162
		(1.323)		(1.369)			(1.434)
Tertiary * Distance to the frontier		-0.893		0.135			14.36*
		(13.25)		(12.28)			(7.323)
Constant	0.965***	0.968***	0.968***	0.970***		0.915***	0.768***
	(0.0126)	(0.0136)	(0.0149)	(0.0152)		(0.0841)	(0.0817)
Observations	111	111	111	111	111	111	111
R-squared	0.236	0.241	0.146	0.148			
AR(1)						0.076	0.068
AR(2)						0.572	0.134
Sargan/ Hansen *p –value*			0.1149	0.1450		0.978	0.955

Table 6: Composition of human capital, distance to frontier and technical progress, 1960-2003

	Pooled OLS	IV	SYS- GMM
TECH	(1)	(1)	(1)
Primary	-0.0223	-0.0244	-0.0223
	(0.0386)	(0.0507)	(0.0511)
Secondary	-0.0439	-0.126	-0.0175
	(0.0756)	(0.111)	(0.100)
Tertiary	0.515	1.027*	0.102
	(0.434)	(0.623)	(0.559)
Distance to the frontier	0.358**	0.391**	0.437***
	(0.179)	(0.186)	(0.115)
Constant	0.961***	0.963***	0.699***
	(0.0124)	(0.0146)	(0.110)
Observations	111	111	111
R-squared	0.166	0.156	
AR(1)			0.013
AR(2)			0.490
Sargan/ Hansen *p -value*		0.1177	0.258

Table 7: Composition of human capital, distance to frontier and technical efficiency, 1960-2003

	Pooled OLS		I V		SYS- GMM	
EFF	(1)	(2)	(1)	(2)	(1)	(2)
Primary	0.0122*	0.0199*	0.0121	0.0153	0.0123	0.0150
	(0.00716)	(0.0107)	(0.00834)	(0.00962)	(0.0109)	(0.0119)
Secondary	0.00918	-0.00805	0.0175	0.0166	0.0150	0.00336
	(0.0196)	(0.0310)	(0.0226)	(0.0302)	(0.0160)	(0.0251)
Tertiary	-0.110	-0.0387	-0.152*	-0.175	-0.104	-0.0549
	(0.0677)	(0.107)	(0.0845)	(0.125)	(0.0597)	(0.0922)
Distance to the frontier	-1.023***	-1.119***	-1.018***	-1.100***	-0.989***	-1.041***
	(0.0629)	(0.0970)	(0.0695)	(0.123)	(0.0584)	(0.179)
Primary* Distance to the frontier		0.503		0.567		0.465
		(0.320)		(0.399)		(0.447)
Secondary * Distance to the frontier		-0.882		-1.083		-1.020
		(0.830)		(0.999)		(1.037)
Tertiary * Distance to the frontier		3.765		3.688		3.051
		(3.743)		(3.992)		(3.168)
Constant	1.004***	1.002***	1.003***	1.003***	1.046***	1.043***
	(0.00247)	(0.00247)	(0.00254)	(0.00265)	(0.0310)	(0.0305)
Observations	111	111	111	111	111	111
R-squared	0.941	0.944	0.935	0.940		
AR(1)					0.096	0.089
AR(2)					0.877	0.424
Sargan/ Hansen *p -value*			0.8707	0.6708	0.290	0.201

Table 8: skilled and unskilled human capital, distance to frontier and productivity growth, 1960-2003

	Pooled OLS		IV		SYS- GMM	
TFP	(1)	(2)	(1)	(2)	(1)	(2)
skilled labour	0.365	0.375	0.660	0.727	0.240	0.171
	(0.341)	(0.357)	(0.450)	(0.500)	(0.408)	(0.342)
unskilled	-0.0232	-0.0250	-0.0484	-0.0695	-0.0204	-0.0181
	(0.0353)	(0.0386)	(0.0458)	(0.0532)	(0.0386)	(0.0323)
Distance to the frontier	-0.496***	-0.435*	-0.441**	-0.0536	-0.376***	-0.535**
	(0.182)	(0.233)	(0.187)	(0.306)	(0.104)	(0.178)
Skilled * Distance to the frontier		0.648		1.230		2.678
		(12.64)		(11.20)		(10.49)
unskilled * Distance to the frontier		-0.153		-0.799		0.281
		(0.775)		(0.649)		(0.518)
Constant	0.966***	0.967***	0.973***	0.981***	0.624***	0.601***
	(0.0124)	(0.0129)	(0.0144)	(0.0167)	(0.0927)	(0.0747)
Observations	111	111	111	111	111	111
R-squared	0.235	0.235	0.146	0.144		
AR(1)					0.001	0.056
AR(2)					0.128	0.252
Sargan/ Hansen *p –value*			0.2520	0.4943	0.158	0.122

Table 9: Skilled and Unskilled human capital, distance to frontier and technical progress, 1960-2003

	Pooled OLS	IV	SYS- GMM
TECH	(1)	(1)	(1)
skilled labour	0.451	0.771*	0.393
	(0.345)	(0.464)	(0.435)
unskilled	-0.0274	-0.0524	-0.0176
	(0.0350)	(0.0460)	(0.0418)
Distance to the frontier	0.359**	0.396**	0.456***
	(0.179)	(0.187)	(0.112)
Constant	0.961***	0.967***	0.668***
	(0.0122)	(0.0143)	(0.106)
Observations	111	111	111
R-squared	0.165	0.156	
AR(1)			0.005
AR(2)			0.145
Sargan/ Hansen *p -value*		0.2296	0.153

Table 10: Skilled and Unskilled human capital, distance to frontier and technical efficiency, 1960-2003

	Pooled OLS		IV		SYS- GMM	
EFF	(1)	(2)	(1)	(2)	(1)	(2)
skilled labour	-0.119*	-0.115**	-0.134*	-0.162*	-0.0884	-0.114
	(0.0610)	(0.0556)	(0.0774)	(0.0876)	(0.119)	(0.0658)
unskilled	0.0115*	0.0107	0.0134*	0.0140	0.00649	0.0103
	(0.00594)	(0.00708)	(0.00704)	(0.00861)	(0.0112)	(0.00731)
Distance to the frontier	-1.023***	-1.016***	-1.018***	-0.973***	-1.006***	-0.997***
	(0.0632)	(0.148)	(0.0703)	(0.204)	(0.0342)	(0.181)
Skilled * Distance to the frontier		2.377		3.000		2.634
		(3.259)		(3.539)		(2.634)
unskilled * Distance to the frontier		-0.0762		-0.178		-0.122
		(0.326)		(0.411)		(0.289)
Constant	1.004***	1.004***	1.003***	1.003***	1.005***	1.004***
	(0.00292)	(0.00365)	(0.00320)	(0.00394)	(0.00397)	(0.00335)
Observations	111	111	111	111	111	111
R-squared	0.941	0.941	0.935	0.936		
AR(1)					0.000	0.134
AR(2)					0.607	0.202
Sargan/ Hansen *p –value*			0.7874	0.9174	0.959	0.463