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Agriculture Productivity in Sub-Saharan Africa[1]

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Introduction.

Sub-Saharan Africa (SSA), the poorest region in the world, is said to be the most important development challenge of the 21st century. It consists of 53 countries with 612 million people, about 10% of the world's total, and covers about 24.2 million square kilometer, 18% of the world's total (FAOSTAT). Gross National Product (GNP) per capita in the region in 1999 was only $510, compared to $1,240 in all developing countries or $2,060 in the Middle East and North Africa (World Bank).

Currently, the majority of population still lives in rural areas and depends on agriculture for their livelihood. In SSA countries agriculture contributes about 35% of the regional GNP and employs more than two-thirds of the total labor force. In most of these countries, agriculture is the largest contributor to foreign exchange, averaging about 40% in the region. Thus, agricultural productivity plays a strategic role in these economies both as a potential source of long-term development and as the essential contributor to sustained food security.

While agricultural productivity gains in the industrialized countries have averaged 2% per year or more in recent decades, and frequently more than that in such developing countries as China and India, most studies of SSA agriculture have indicated agricultural productivity losses during the 1970's and 1980's. On the other hand a recent study by FAO used input weights for Brazil and India to weight agricultural input changes in 47 SSA countries, and using this approach, calculated average SSA productivity gains of about 0.5% annually from 1961 to 1996. We cannot be very confident of this estimate because of the weighting procedure, but the report serves as a reminder that we are not yet very certain whether SSA agriculture has gained or lost productivity in the past half-century, let alone an understanding of the contributing factors.

The present study is thus an effort to improve our confidence in the estimates of agricultural productivity in SSA, and to identify important contributing factors. Here we examine the agricultural productivity performance of a panel of 41 SSA countries for 1961 to 1999, using a stochastic frontier specified as a Fourier flexible form. This approach allows us to examine whether variability in productivity gains is related in important ways to institutional and political environment, and to specify the time path of productivity in a flexible manner.

` Section Two Literature Review

Studies on SSA agriculture, especially in the field of agricultural productivity, are few relative to the importance of the topic. Many of them are limited to one or a few countries instead of SSA as a whole, for example, Thirtle *et al*'s studies in Zimbabwe and Morrison's work in Burkina Faso and Mali.

Several important investigations on total factor productivity (TFP) growth in SSA have been made during the last decade. Block estimated a system of aggregated production functions with equal slope coefficients and TFP growth is computed from the difference between intercepts of two consecutive production functions. He reported average annual TFP changes between –0.5% and 1.6% for 39 SSA countries. Thirtle, Hardley, and Townsend estimated a low annual TFP growth rate of 0.838%, using an input-based Malmquist index for 22 SSA countries during 1971-1986. Investments in infrastructure, research and development, and secondary education were found to explain variations in technical progress. Lusigi and

Thirtle estimated that the average rate of TFP growth in Africa was 1.27% per year for the period 1961-1991 by calculating input-based multilateral Malmquist indexes of TFP growth for agriculture in 47 African countries. They also estimated a deterministic frontier model (using COLS) and a stochastic frontier and found that land quality and R&D contributed to output growth. Recently, this figure was modified to –0.86% per year by Suhariyanto, Lusigi, and Thirtle, after changing the variables for modern inputs from ratios of variables to land to simple levels.

In the 2000 annual report of Food and Agricultural Organization of the United Nations (FAO), agricultural growth rates for 89 developing countries were calculated as a Tornqvist-Theil index, using input cost shares from studies in Brazil and India. This study estimated the average productivity growth rate to be 0.49% per year for 1961-1996. Eleven of fourteen countries were estimated to have negative TFP growth rates, which researchers attributed to land degradation. Yu, Fulginiti, and Perrin used a nonparametric Malmquist to examine agricultural productivity in 37 SSA countries from 1961 to 1998, and found a deterioration of 1.1% per year.

The studies to date of productivity trends in SSA provide conflicting and incomplete estimates. Analysis with a wider sample of countries including those with higher agricultural productivity have been important in quantifying the relative importance of factors affecting productivity performance, such as modern input use, research, infrastructure, and relative prices. Many of these studies found that TFP for the agricultural sector has declined among developing countries. Fulginiti and Perrin (1997) reported deterioration in more than half of the less developed countries (LDCs) sduring 1961-85 in a sample of eighteen countries that included three in SSA. Rao and Coelli studied 97 countries and found that 9 out of 22 SSA countries exhibited negative TFP growth in 1980-1995. Arnade examined 70 countries and found productivity regress in 5 out of 6 SSA countries over 1961-1993. The weight of evidence from these studies is that SSA agricultural productivity declined between 1960 and 1990.

Some researchers have used the concept of partial productivity to examine sources of variations in agricultural performance. Frisvold and Ingram indicated that growth in the stocks of traditional inputs (land, labor, and livestock) remained the dominant source of agriculture growth in 28 SSA countries for 1973-1985, and estimated that land productivity grew at an annual rate of 1.5-1.8% for most countries. Kawagoe, Hayami, and Ruttan showed that labor productivity in LDCs can be increased by investments in education, research, and modern technical inputs. Labor productivity in agriculture was also investigated by Craig, Pardey, and Roseboom in a study of 67 developing countries, including 25 SSA countries. They found that conventional inputs explain nearly three-fourths of the variation in labor productivity across countries.

Chan, *et al*., used a similar labor productivity model and confirmed that traditional inputs continued to be a dominant source of labor productivity growth and modern technology has not yet had a pervasive impact on Africa agriculture. Based on a labor productivity model, Wiebe, *et al*.(1999) observed decreasing return to scale in SSA (which agrees with Chan, *et al*.) and determined that land quality had a significant impact on productivity. They initially estimated significant and negative fertilizer response in SSA, but further analysis (2000) showed the coefficient on fertilizer to be significant and positive.

Acemoglu, Johnson, and Robinson hypothesized that African countries are poorer not because of cultural or geographic factors, but mostly because of worse institutions and governance. This suggests that these factors should be considered in determining the causes of agricultural productivity performance.

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A Model to Measure Productivity.

Productivity is defined as output per unit of input. Productivity growth aims at capturing output growth not accounted for by growth in inputs. In this context two questions immediately arise. First, what are the components of productivity growth? Second, what potential institutional and socio-political factors have affected agricultural productivity performance in SSA in the last four decades? We will try to shed light on both questions.

Among the many alternatives available to estimate productivity growth, the one we adopt is that pioneered by Solow and Griliches and used by many others in the multi-country context. We use a production function to break down the growth rate of aggregate output into contribution from the growth of inputs versus productivity change. We start with a standard neoclassical production function:

(1) $$Y_{it} = f(x_{it}; b)$$

where Y_{it} is output of the *i*-th country in time period t, x_{it} is an $nx1$ vector of inputs for the *i*-th country in time period t, and b is a vector of unknown parameters.

Following Jorgenson and Griliches, and consistent with the definition of productivity growth introduced above, we specify total factor productivity growth (TFP) as a residual:

(2) $$\dot{TFP}_{it} = \dot{Y}_{it} - \dot{x}_{it} = \dot{Y}_{it} - \sum_{n} s_{itn}\, \dot{x}_{itn}$$

where a dot over a variable indicates its rate of change, and s_{itn} is the observed expenditure share of input *n*, for country *i* in year *t*. Equation (2) assumes technical and allocative efficiency along with constant returns to scale.

In this context our first task is to relax the restrictive conditions imposed on equation (2) in order to identify the potential components of TFP growth. We then follow Kumbhakar and Lovell and modify equation (1) to allow for technical and allocative inefficiencies, for departures from constant returns to scale, and for the possibility of shifts of the production function representing the introduction of new techniques of production. We rewrite the production function the following way, re-labeling it a production frontier :

(3) $$Y_{it} = f(x_{it}, t; b)\exp(-u_{it})$$

where t is the technology index, and u_{it} is a non-negative random variable associated with technical inefficiency across production units. In our case, it accounts for heterogeneity across countries that can cause departures from maximum potential output. If nothing is assumed in terms of returns to scale and allocative efficiency in inputs markets, then TFP growth using the production function in equation (3) and dropping the *it* subscripts for simplicity, yields:

(4) $$\dot{TFP} = TC + \sum_n (e_n - s_n)\dot{x}_n + EC$$

where a shift of the production frontier representing technical change is

(5) $$TC = \frac{\partial \ln f(x, t; b)}{\partial t},$$

the elasticity of output with respect to input n is

(6) $$e_n = \frac{\partial \ln f(x, t, b)}{\partial \ln x_n},$$

and the scale elasticity is

(7) $$e = \sum_n e_n$$

which provides a measure of returns to scale in production. The last term in equation (4) represents technical efficiency change and is obtained as:

$$(8) \qquad EC = -\frac{\partial u}{\partial t}$$

which indicates that a country is more efficient in the use of its inputs when EC is positive.

EC can be interpreted as the rate at which a country moves toward or away from the production frontier, which itself may be shifting through time. We can rewrite equation (4) so as to answer our first question:

$$(9) \qquad \dot{TFP} = TC + \underbrace{(\varepsilon - 1)\sum_n \frac{\varepsilon_n}{\varepsilon}\dot{x}_n}_{scale} + \sum_n \left(\frac{\varepsilon_n}{\varepsilon} - s_n\right)\dot{x}_n + EC$$

where the right hand side terms represent the different components of productivity growth, that is, technical change, scale change, an adjustment for input growth when competitive conditions in the input markets are not necessarily maintained, and efficiency change. Due to lack of information on prices and actual expenditure shares, we are unable to calculate the fourth term of expression (9) so we assume that $s_n = \frac{\varepsilon_n}{\varepsilon}$ and the decomposition simplifies to

$$(10) \qquad \dot{TFP} = TC + (\varepsilon - 1)\sum_n \frac{\varepsilon_n}{\varepsilon}\dot{x}_n + EC .$$

The technical efficiency change component requires a little more explanation given that it will also be the basis for information that will lead us to answer the second of our questions, the identification of institutional and political factors that underlie differential productivity growth performance across countries in SSA. Technical inefficiency across the production units involved is captured in the production frontier of equation (3) by the non-negative random variable u. The ratio of observed output for the *i*-th country relative to its potential output defined by the production frontier, given the levels of inputs, is used to define the technical efficiency of the *i*-th country in period *t*:

$$(11). \quad TE_{it} = \frac{y_{it}}{f(x_{it};b)} = \frac{f(x_{it};b)\exp(-u_{it})}{f(x_{it};b)} = \exp(-u_{it})$$

This measure of technical efficiency does not depend on the level of the factor inputs and takes on values zero to one, with a value of one indicating full technical efficiency. It can also be thought of as indicating the size of the output of the *i*-th country at time *t* relative to the output produced by a fully efficient country using the same input vector. The ratio of *TE's* between two periods gives an alternative way of calculating *EC*.

Given that the *TE* term indicates discrepancies in the productivity performance across countries, the frontier methodology lends itself to the inclusion of potential determinants of country heterogeneity which we refer to as 'efficiency changing variables'. We specify a frontier model where the technical inefficiency effects are defined to be an explicit function of country-specific institutional and socio-political factors that we hypothesize have influenced the differential performance of these countries. We then specify the technical inefficency effect u_{it} of the *i*-th country in the *t*-th period as a truncated N(μ_{it}, s ^{2}) distribution, where

$$(12) \qquad m_{it} = h_{it} d \, ,$$

in which h_{it} is a (1x*p)* vector of variables that influence the efficiency of the country, such as institutional and socio-political conditions, and *d* is (*p*x1)vector of unknown scalar parameters to be estimated.

Data and Estimation

FAO data on output and conventional agricultural inputs (land, labor, fertilizer, tractors and animals) are reasonably complete for 41 SSA countries for 1961-1999, and are available at the FAOSTAT website. These data have been used in nearly every previous study of agricultural productivity in SSA countries. The data are based on reports submitted to FAO that are frequently incomplete or missing. Some of the data on the website have therefore been estimated by FAO, and some of the data series are obviously rather casually generated (the same number for many years followed by a different number for many years; occasionally abrupt year-to-year changes; etc.) Nonetheless, an examination of other international agency reports reveals that these are virtually the only data of this type available, despite their dubious accuracy in many instances.

Agricultural output is expressed as the quantity of agricultural production in millions of 1989-1991 "international dollars". Agricultural land is measured as the sum of arable land, permanent crops and permanent pastures, in 1,000 hectares. Agricultural labor is measured as the number of persons who are economically actively engaged in agriculture, in thousands. The livestock variable is a weighted average of the number of animals on farms (weights are: camels 1.1; buffalo, horses and mules 1.0; cattle and asses 0.8; sheep and goats 0.1; pigs 0.2; fowl 0.01), in 1,000's. The farm machinery variable we use is simply the number of agricultural tractors. Fertilizer is quantity of fertilizer plant nutrient consumed (N plus P_2O_5 plus K_2O), in metric tons.

Our approach is to consider productivity to constitute changes in output, so measured, for given levels of this set of traditional inputs. Some measurable factors that we hypothesize may impact this productivity include the quality of labor and land, and institutional or political factors such as war that affect the ability or incentive of producers to extract output from a given bundle of traditional inputs. These variables we call efficiency-changing variables, because systematic differences in productivity in our model are defined as differences in efficiency. This effort to explain the differences among countries and through time follows a tradition originated by Hayami and Ruttan, that includes Kawagoe, Hayami and Ruttan who found that labor productivity can be increased by investments in education and research; Fulginiti and Perrin who suggested positive productivity effects of public research, land quality and human capital in 18 LDC countries; Antle who also found that research and infrastructure contribute positively to agricultural productivity; and Schuh and Norton who found that education had a significant influence on agricultural output.

The efficiency-changing variables we consider are as follows.

a) Labor quality - adult illiteracy rate and life expectancy at birth are taken from World Development Indicators (World Bank);

b) Land quality – both a quality index and percentage of irrigated land are used as proxies for land quality. The land quality index is the percentage of IGBP class 12 cropland, as identified by USGS, that is in land quality class 1, 2 or 3, as identified by NRCS (Wiebe et al. (1999)). It is obtained by combined high-resolution land-cover data and spatially referenced soil and climate. It is available at ERS, USDA for 35 SSA countries, and we have constructed estimates for missing countries by averaging scores from neighboring states. The percentage of irrigated land was calculated from the ratio of irrigation land (World Bank) over total agricultural land (FAOSTAT). Missing values were estimated by extrapolation of the growth rates of the three years closest to the missing observations.

c) Institutional/political environment - Differences in colonial heritage persist in political, economic, cultural, military, financial and religious structure. We utilize dummy variables for former British and French colonies (versus Belgian, Dutch and Italian as reference), and a dummy variable equal to 1.0 if the country was independent at the time of the observation. These data were collected from Encyclopedia Britannica. Because war could clearly affect productivity, we constructed a dummy variable to indicate armed conflict by country and year from 1970 to 1999, based on data from Wallensteen and Sollenberg, and Sivard. Finally, we also constructed two dummy variables to represent the Freedom House index of political rights and civil liberties, with countries categorized as free or partly free (contrasted with not free), from 1972 to 1999. We extrapolated growth rates of index values for the three closest years to estimate missing values.

In order to implement the model suggested above with the objective of measuring productivity growth in SSA countries we need to choose a particular functional form to approximate the production frontier in (3). Two mathematical series have been used to approximate production structures. These are Taylor series and Fourier series. Taylor's theorem gives a locally second-order approximation of any function at a certain point but will not warrant a close approximation for the whole sample. Hence, estimations using a global method, such as OLS, will generally give biased and inconsistent estimates of the derivatives of Taylor-type functions like the translog, the generalized Leontieff, or the generalized quadratic. Conclusions drawn from these models are of limited generality because they merely express empirical results with respect to the performance of these models at the neighborhood of an approximation point. As demonstrated by White, except for highly restrictive conditions, ordinary least squares estimates of a second-order polynomial such as a translog fail to correspond to the true Taylor series expansion of the underlying function at the expansion point and hence gives biased parameter estimates and test statistics. Capalbo also noticed that empirical results and theoretical consistency are sensitive to model specification, and curvature properties and monotonicity hold only locally for a function like the translog.

We choose to approximate the production frontier in equation (3) with a Fourier flexible form. The Fourier series is defined as a linear combination of trigonometric and polynomial terms that have the capability of representing exactly any well-behaved multivariate function. It differs fundamentally from Taylor series in that it has a variable number of parameters and a known bound to approximate an arbitrary function well over the entire range of data. This is possible because the sine and cosine functions are mutually orthogonal and function space spanning. Thus an arbitrary function may avoid function misspecification with a Fourier series even without knowledge of the true form.

There are papers in the literature that compare the two approximation methods. Gallant (1981) noticed that the translog power curve only increases locally while Fourier form gains full power as departures from the null case become extreme. Wohlgenant compared the Fourier form with a translog and a generalized Leontief functional form and showed that the Fourier flexible form was superior on both theoretical and empirical grounds. The translog cost function has been found to be biased by Mitchell and Onvural and less favorable than the Fourier flexible form by Huang and Wang.

The Fourier flexible form introduced by Gallant and his colleagues is a semi-nonparametric form because it combines a standard linear and quadratic form with a non-parametric Fourier series for a closer approximation. The procedure for constructing a Fourier flexible form was described by Gallant (1981, 1982, 1984), and more detailed discussions can be found in Elbadawi, Gallant and Souza, Chalfant and Gallant, Eastwood and Gallant and Gallant and Souza. The Fourier flexible form for a non-periodic function is written as:

(13) $$g_K(x) = \mathrm{b}_0 + b'x + \frac{1}{2}x'Cx + \sum_{\mathrm{a}=1}^{A}\{\mathrm{b}_{0\mathrm{a}} + 2\sum_{j=1}^{J}[\mathrm{b}_{j\mathrm{a}}\cos(jk_{\mathrm{a}}'x) + \mathrm{a}_{j\mathrm{a}}\sin(jk_{\mathrm{a}}'x)]\}$$

where x is a $Nx1$ vector of scaled inputs (scaled between 0 and 2π,) b is a $Nx1$ vector of coefficients, C is a NxN symmetric matrix of coefficients, and u, v are AxJ matrices of coefficients. $k_a^{'} = [k_{x_1}, k_{x_2}, \ldots, k_{x_N}]'$ are multi-indices ($Nx1$ elementary vectors).

It is clear that the Fourier flexible form as a global approximation dominates the commonly used translog form. This global property is particularly important in production, where scales of inputs and outputs are often far from the mean. However, increasing the number of parameters reduces approximation error while increasing the variance of test statistics used in hypothesis testing. As Chalfant observed, bias-instability trade-offs can be substantial although the Fourier form features desirable property of unbiasedness.

The Fourier flexible functional form has been used to approximate dual cost structures but it has not been used to approximate a primal production frontier. This paper does so. We follow Eastwood and Gallant to select the order of expansion to use. This leads us to a choice of of A=27, J=1.

Assuming symmetry, the production frontier to estimate for SSA agriculture is:

$$\ln Y_{it} = b_0 + \sum_{i=1}^{5} b_i \ln x_{it} + \sum_{i=1}^{5} \sum_{j \geq i} b_{ij} \ln x_{it} \ln x_{jt} + \sum_{i=1}^{5} b_{it} \ln x_{it} t + b_t t + b_{tt} t^2$$

$$(14) \quad + \sum_{i=1}^{6} [b_i \cos(z_{it}) + a_i \sin(z_{it})] + \sum_{i=1}^{6} \sum_{j=i}^{6} [b_{ij} \cos(z_{it} + z_{jt}) + a_{ij} \sin(z_{it} + z_{jt})]$$

$$+ (v_{it} - u_{it})$$

where Y is agricultural output and x is the vector of inputs (land, labor, livestock, machinery and fertilizer,); t is a time trend used as a proxy for technical change; the z*'s* are scaled values of *lnx's* and t. u_{it} is the one sided introduced before that captures heterogeneity across countries and is the basis for differences in technical efficiency. In order to allow for measurement error and other random factors we augment the production frontier by adding a random error $v_{it.,}$ an i.i.d. $N(0, s_v^2)$ that is independent of u_{it} which was assumed half $N(\mu, s_U^2)$. This is a *stochastic* frontier production function.

Next we present the specifications for the inefficiency effects that will help understand sources of differential productivity performance across countries. As was stated before we make the technical inefficiency term a function of institutional and socio-political variables. Due to data availability, two efficiency models are introduced that accommodate different sampling period.

In model 1, estimated with data from 1961 to 1999, we specify technical inefficiency as

$$m_{it} = d_0 + d_1 ILL + d_2 LIFE + d_3 IRRIGATE + d_4 LQI + d_5 INDEP + d_6 UK + d_7 FRANCE \quad (15)$$

where d is a 1x8 vector of parameters to be estimated, ILL is adult illiteracy rate, LIFE is life expectancy at birth, IRRIGATE is the percentage of irrigated land in agricultural land, LQI is the land quality index, INDEP is the dummy variable indicating independence, UK and FRANCE are dummy variables for pre-colonial metropolitan countries.

Model 2 adds institutional variables, armed conflicts and democracy dummies, to model 1, and it is estimated for periods the data are available, 1972-1999. The technical inefficiency model is

$$m_{it} = d_0 + d_1 ILL + d_2 LIFE + d_3 IRRIGATE + d_4 LQI + d_5 INDEP + d_6 UK + d_7 FRANCE + d_8 WAR + d_9 FREE + d_{10} PARTLYFREE \quad (16)$$

Equations (14) and (15), or (14) and (16) are estimated using the maximum-likelihood (ML) method suggested by Coelli. Aigner Lovell and Schmidt derived the log-likelihood function for this model and expressed the likelihood function in terms of the two variance parameters $s^2 = s_u^2 + s_v^2$ and $f = s_{u/}\, s_v$. Battese and Corra suggests that the parameter ? = s_u^2/ s^2 be used instead because it has values between zero and one. The ML estimates of the parameters *ß*, s, ?, and *d* re obtained using Coelli's FRONTIER program.

Estimates of Productivity for SSA

Several nested hypotheses are tested using likelihood ratio tests, with the objective of finding the most appropriate form to represent the production relationship and to estimate TFP growth and its components.

First a test to check the nature of technical change is performed. Hicks-neutrality implies that the coefficients of the interactions between the logs of inputs and the time trend are all zero. That is, we test $b_{1t} = b_{2t} = b_{3t} = b_{4t} = b_{5t} = 0$. The log-likelihood function values for both model 1 and model 2 are summarized in table 1 and 2. The null hypothesis of Hicks-neutral technical change is rejected.

The next hypothesis asks whether there has been any technical change over the sample period. This test imposes a restriction that all the coefficients associated with the time trend be zero. The results shows a likelihood ratio of 225.04 (model 1) and 206.76 (model 2), implying the occurrence of technical change during sample period.

To test the null hypothesis that the production structure is of a tranlog type is of interest given the wide use of this form in production analysis. If this hypothesis is not rejected, the estimation and analysis is dramatically simplified. The null hypothesis is

$H_0 : u_i = v_i = u_{ij} = v_{ij} = 0$ for all i and j.

The value of the log-likelihood functions is reduced dramatically after all trigonometric terms are dropped and the null hypothesis is strongly rejected. This indicates the Fourier series terms are significant additions to the model and the popular translog model might be misleading.

A number of tests are also performed on the technical inefficiency model. First, a test of the null hypothesis of no technical inefficiency is done. If the null hypothesis is true, the technical inefficiency error term, *u*, should be omitted from (13) and the model can be estimated with OLS. The null hypothesis is:

$$H_0 : g = d_0 = d_1 = ... = d_7 = 0 \qquad \text{model 1}$$

$$H_0 : g = d_0 = d_1 = ... = d_{10} = 0 \qquad \text{model 2}$$

The LR test rejects H_0, confirming the presence of technical inefficiency.

Next, we test for the influence of country specific factors on the degree of technical inefficiency. Thus a test of the hypothesis that

$$H_0 : d_1 = ... = d_7 = 0 \qquad \text{in model 1 and}$$

$$H_0 : d_1 = ... = d_{10} = 0 \qquad \text{in model 2}$$

is performed and the results are listed in the final rows of table 1 and 2. The likelihood ratio statistic indicates rejection of the null hypothesis of no technical inefficiency.

With the conclusion of the above tests, the appropriate model appears to be the translog Fourier flexible form model without any restrictions. Most of the parameter estimates are significant (78 of 91 in model 1 and 81 of 94 in model 2.)

Table 3 provides the estimates of elasticities, returns to scale and technical change for both models. In model 1, the production elasticities of output with respect to inputs, measured at mean, are of the correct sign for labor, machinery and fertilizer, but are negative (though small) for land. The estimated scale elasticity of 0.890 indicates decreasing returns to scale.

The last row shows the rate of technical change, estimated at the mean with value -0.002, implying that SSA countries have experienced technical regression over the sample period, that is, the production frontier has shrunk toward the origin at an average rate of –0.2% per year.

Results from model 2 indicate a rate of technical progress of 1.4% per year, but land elasticity is negative and large (-.3) and livestock elasticity is negative though tiny. The estimated labor elasticity of .94 is implausibly large, and the elasticities of machinery and livestock are suspiciously large, as well. Thus, although model 2 offers some hope that technical progress has actually occurred, the estimates are clearly not believable, and will require further investigation to identify the reasons for that.

We now turn to examine the parameters of the efficiency-changing variables associated with the error term *u* (that is, the δ's). Recall that negative values of these parameters imply improved efficiency. The maximum likelihood estimates of several of these parameters are both of the expected negative sign and significant, namely, life expectancy, illiteracy (in model 1), irrigation, and independence (in model 1). The land quality index, however, is significantly positive, indicating that higher land quality reduces efficiency. Either the index is a grossly poor measure of quality, or the estimate is confounded by multicollinearity or some other econometric difficulty that will take additional effort to identify.

We had no a priori sign expectation for British and French colonial histories. The results of model 1 suggest that both of these empires left inefficient agricultural colonies relative to Belgian, Dutch and other colonial masters. However, when civil liberties and armed conflict variables are added in model 2, the French effect is reversed and the British effect is substantially reduced. The war coefficient is tiny and not significantly different from zero (consistent with the results of Wiebe, Soule, Narrod and Breneman), but the civil liberties variables significantly improve efficiency (consistent with estimates by Chan-Kang, *et al*., for a labor productivity function for African agriculture.)

Taken at face value, the technical efficiency results of the two models suggest that apart from a legacy of poor civil rights, former French colonies are quite efficient – it's just that this efficiency is lost in these countries in general because of the poor civil rights. The British colonies appear to be basically less efficient, with the inefficiency compounded by poor civil rights relative to countries that were never French or British colonies. Given the somewhat shaky plausibility of other parameter estimates of these models, however, these hypotheses bear considerable more scrutiny before they can be maintained with any confidence.

According to Battese and Corra (1977), $g = s_U^2 / (s_V^2 + s_U^2)$ can be loosely interpreted as an indication of the amount of unexplained variation in technical inefficiency, relative to the sum of variance in both u and v. Here, $s^2 = s_U^2 + s_V^2$ is significantly different from zero in both models. Comparing model 2 with model 1, the total variance decreased by half, with the bulk of the decrease clearly occurring in the variance of u, the unexplained portion of variations in technical efficiency.

The technical efficiencies of each country in each year were estimated from the model and their average is plotted against time in figure 1. The plot for model 1 shows an average efficiency around 0.8, with a very slight decrease over time. The plot for model 2 averages somewhat less than 0.7, and shows a marked decline through time.

Technical change as specified by the Fourier model is sufficiently flexible to follow virtually any time path. The plot of the estimated path of technical change from model 1 in Figure 2 shows a surge in the first half of the 1960's, a second surge in the early 1980's, and a third surge in the late 1990's. It is not at this point evident to us what new technologies or weather patterns might have contributed to these surges.

TFP change is a composite of technical change, scale change, and efficiency change. The calculated average rates of TFP change by country, from model 1, are summarized in table 5. Only 9 of the 41 countries had positive TFP growth over the 1961-99 period, while 32 countries exhibit deterioration in all components of TFP change. On average over all countries, the estimated productivity decline is 0.57% per year. Technical change appears to be the main determinant for productivity development. Since agriculture in SSA shows decreasing return to scale, scale changes are negative for most of countries except for Mauritius and South Africa.

In an earlier study, we used a nonparametric frontier approach to examine agricultural productivity in a subset of these countries (Yu, Fulginiti and Perrin.) The mean efficiency estimated in that study was 0.747, which is close to the mean technical efficiency 0.8 from the econometric approach in the present study. In the earlier study, average technical efficiency and technical change both regressed over time. Results from this paper are consistent with that previous study, and with most other studies, but quite inconsistent with the FAO study that estimated productivity gains of 0.5% per year over this period in SSA.

Summary and Conclusion

This study has estimated a Fourier translog production frontier to examine agricultural productivity in 41 sub-Saharan Africa (SSA) countries during 1961-1999. The primary empirical result is that only nine of these countries experienced productivity improvements, and the average productivity across all counties declined by an average of –0.57% per year.

This general conclusion is consistent with our own previous result using a non-parametric analysis of a similar data set, and it is consistent with a number of other studies of SSA agriculture. These results all contradict those of a recent FAO study that estimated productivity increases of +0.5% per year over essentially the same period.

Decomposition of this poor performance record indicated a mean efficiency level of about 0.8, with an average annual decline in efficiency of about .06% of potential output each year. Efficiency-changing variables such as literacy and irrigation contributed signficant improvements in efficiency. We also found that civil liberties had significant positive effects on efficiency, while countries that had previously been colonies of Britain or France had significantly poorer efficiency performance. Technical change, on average, declined by 0.21% per year, and scale efficiency fell by 0.29% per year.

We conclude that the Fourier translog specification has merit in studies such as this. Statistical tests strongly supported this conclusion, and the flexibility of the time path of productivity is clearly advantageous. In this particular study, that time path showed surges of productivity in the 1960's, early 1980's and late 1990's that warrant further investigation.

We cannot conclude that we have sufficiently robust estimates of agricultural productivity and its components in SSA. Our estimates reveal instability in some of the parameters that demands our attention in the near future. The usefulness of the political variables encourages us to explore others of these measures more fully. We believe that weather patterns may explain a substantial portion of estimated inefficiencies, and may improve the stability of other parameter estimates. Agricultural productivity gains are clearly an important goal for SSA, and further efforts to determine the actual path of productivity and factors that have determined it seem well warranted.

Table 1. Hypotheses testing model 1

Restrictions	model description	log likelihood	likelihood-ratio statistic (lamda)	chi-square critical value (5%)	decision
none	translog Fourier	208.15			
Hicks-neutral	no time interaction	193.24	29.82	11.1	reject H0
no technical change	no time trend terms	95.63	225.04	32.7	reject H0
translog	no trigonometric terms	-359.50	1135.30	43.8	reject H0
gamma= delta=0	translog Fourier (OLS)	29.48	357.34	15.5	reject H0
delta=0	translog Fourier (OLS)	29.48	357.34	14.1	reject H0

Table 2. Hypotheses testing of model 2

Restrictions	model description	log likelihood	likelihood-ratio statistic (lamda)	chi-square critical value at 5%	decision
none	translog Fourier	287.33			
Hicks-neutral	no time interaction	239.21	96.24	11.1	reject H0
no technical change	no time trend terms	156.95	260.76	32.7	reject H0
translog	no trigonometric terms	-236.21	1047.1	43.8	reject H0
gamma= delta=0	translog Fourier (OLS)	107.87	358.92	15.5	reject H0
delta=0	translog Fourier (OLS)	107.87	358.92	14.1	reject H0

Table 3. Estimates derived from the translog Fourier flexible form

description	model 1 estimate at mean	model 2 estimate at mean
Land elasticity	-0.086	-0.309
Labor elasticity	0.713	0.940
Livestock elasticity	0.059	-0.007
Machinery elasticity	0.166	0.222
Fertilizer elasticity	0.038	0.087
Returns to scale	0.890	0.932
Technical change	-0.002	0.014

Table 4. . ML Estimates of the technical efficiency coefficients

	model 1		model 2	
	estimate	t-ratio	estimate	t-ratio
delta0	-0.928	-7.97	0.556	4.50
life expectancy	-0.003	-4.01	-0.005	-8.91
adult illiteracy	0.007	3.84	0.003	1.58
irrigation	-0.001	-21.04	0.000	-6.92
land quality index	0.017	12.08	0.005	10.90
independence	-0.170	-4.20	-0.005	-0.10
UK	1.379	17.90	0.269	7.87
France	0.664	9.84	-0.454	-10.32
war			-0.008	-0.34
free			-0.057	-3.66
partly free			-0.020	-0.53
sigma_squared	0.07	21.15	0.036	22.06
gamma	0.58	15.71	0.028	6.33

Table 5. TFP and its components

	mean efficiency	EC	SC	TC	TFP
Angola	0.97	-0.01	-0.34	-0.41	-0.76
Benin	0.92	0.27	-0.21	-0.01	0.05
Botswana	0.55	0.08	-0.23	1.43	1.28
Burkina Faso	0.80	-0.32	-0.51	-0.48	-1.32
Burundi	0.94	-0.02	-0.50	-1.77	-2.30
Cameroon	0.95	0.02	-0.31	-0.24	-0.53
Cape Verde	0.96	0.02	-0.22	0.00	-0.21
Central	0.91	0.00	-0.21	-0.25	-0.46
Chad	0.89	-0.14	-0.33	0.43	-0.04
Zaire	0.96	-0.08	-0.27	-1.89	-2.24
Congo	0.96	-0.04	-0.25	-0.19	-0.48
Côte d'Ivoire	0.92	0.18	-0.46	-0.41	-0.70
Ethiopia PDR	0.58	-0.39	-0.41	-0.52	-1.33
Gabon	0.93	-0.06	-0.34	-0.52	-0.92
Gambia	0.67	-0.79	-0.37	0.14	-1.02
Ghana	0.75	0.37	-0.34	-0.79	-0.76
Guinea	0.93	-0.04	-0.46	-0.84	-1.34
Guinea-Bissau	0.95	0.01	-0.33	-0.02	-0.34
Kenya	0.55	-0.13	-0.35	-0.21	-0.70
Lesotho	0.62	-0.18	-0.31	0.96	0.46
Liberia	0.95	-0.04	-0.24	-1.59	-1.87
Madagascar	0.96	0.12	-0.29	-0.11	-0.27
Malawi	0.49	-0.16	-0.36	-0.79	-1.30
Mali	0.84	0.17	-0.43	-0.01	-0.28
Mauritius	0.70	-0.62	0.03	1.03	0.45
Mozambique	0.95	0.04	-0.23	-1.23	-1.41
Namibia	0.68	0.22	-0.18	0.88	0.92
Niger	0.93	-0.03	-0.52	-0.49	-1.03
Nigeria	0.65	0.05	-0.37	-0.62	-0.94
Rwanda	0.92	0.16	-0.36	-1.73	-1.93
Senegal	0.91	-0.13	-0.29	0.04	-0.38
Sierra Leone	0.81	0.00	0.00	-0.67	-0.67
Somalia	0.83	-0.42	-0.24	0.39	-0.26
South Africa	0.96	0.06	0.09	1.41	1.55
Sudan	0.97	0.04	-0.29	0.31	0.06
Swaziland	0.47	0.17	-0.13	1.53	1.57
Tanzania	0.61	-0.01	-0.23	-0.39	-0.62
Togo	0.92	-0.22	-0.37	-0.12	-0.71
Uganda	0.71	-0.92	-0.35	-1.49	-2.75
Zambia	0.41	0.04	-0.29	0.20	-0.04
Zimbabwe	0.41	0.18	-0.26	0.42	0.35
mean	0.80	-0.06	-0.29	-0.21	-0.57

Figure 1. Efficiency measure over time in SSA

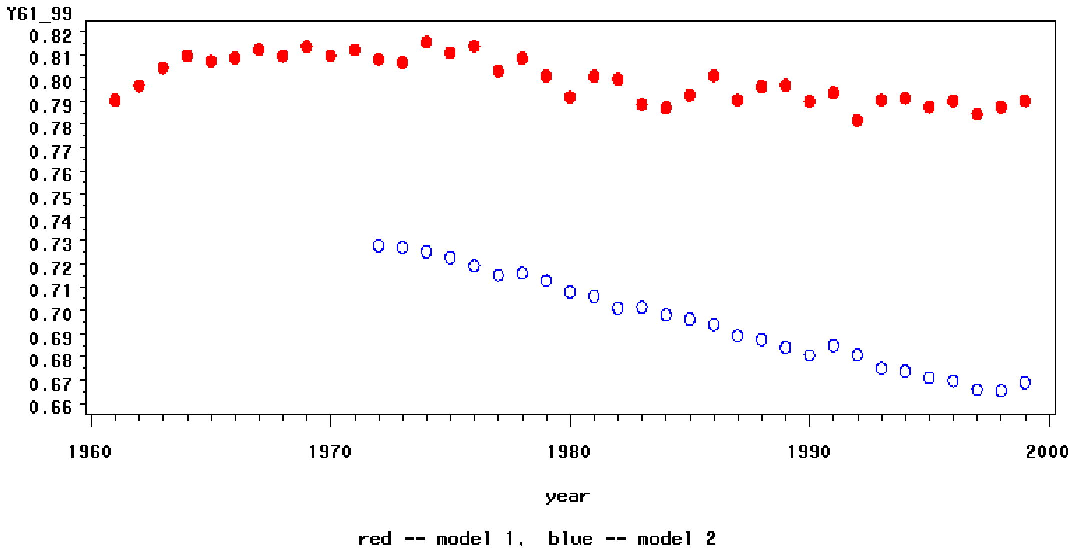
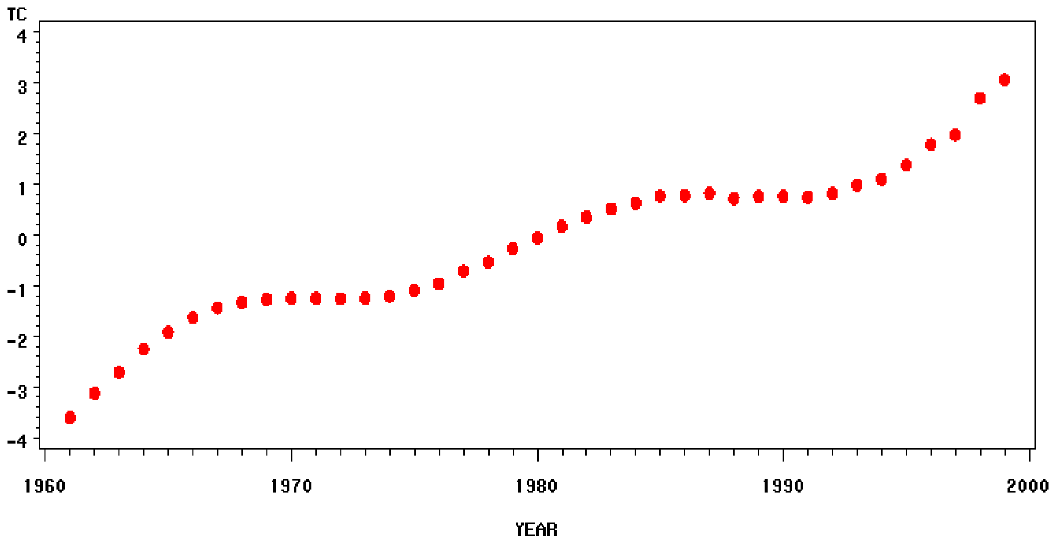


Figure 2. Technical change (in %) over time in SSA



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