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Institutions and Agricultural Productivity in Sub-Sahara Africa[1]

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Abstract: Agricultural productivity in 41 Sub-Saharan Africa (SSA) countries from 1960 to 1999 is examined by estimating a semi-nonparametric Fourier production frontier. Over the four decades the estimated rate of productivity change was 0.83% per year, although the average rate from 1985-99 was a strong 1.90% per year. Former UK colonies exhibited significantly higher productivity gains than others, while Liberia and countries that had been colonies of Portugal or Belgium exhibited net reductions in productivity. We measure a significant reduction in productivity during political conflicts and wars, and a significant increase in productivity among those countries with a measure of political rights and civil liberties.

Key Words: Sub-Saharan Africa, agricultural productivity, institutions, Stochastic Frontier, Fourier Functional Form.

Introduction.

Sub Sahara Africa is one of the world's poorest regions. Its population (over 600 million) and land area are approximately three times that of the USA. The region's economies are heavily dependent on agriculture, which accounts for two-thirds of the labor force, 35% of GNP and 40% of foreign exchange earnings. Productivity performance in the agricultural sector is thus critical to improvement in overall economic well-being in Sub-Saharan Africa (SSA), and it has therefore been the subject of at least six reasonably comprehensive studies (Block (1994), Frisvold and Ingram (1995), Thirtle, *et al*.(1995), Lusigi and Thirtle (1997), Rao and Coelli (1998), Suharyanto, *et* *al.*(2000) and FAO (2000).) These studies, though they have covered different time periods and different sets of SSA countries, have been reasonably consistent in reporting positive average productivity gains during the 1960's, regression or no gain in productivity during the 1970's, with a recovery to positive gains during the 1980's and early 1990's. The present study aims to provide a more comprehensive understanding of agricultural productivity in this region, and the potential role of colonial heritage and other institutional factors that might explain the differences between counties.

Analytical Approach.

Productivity is defined as output per unit of input. Productivity growth aims at capturing output growth not accounted for by growth in inputs. We address two questions about agricultural productivity in SSA. First, what has been the rate of productivity growth? Second, what potential institutional and socio-political factors have affected agricultural productivity performance in SSA in the last four decades?

Among the many alternatives available to estimate productivity growth, the one we adopt is the production function approach pioneered by Solow and Griliches and used by many others in the multi-country context. Aigner, Lovell and Schmidt and Meeusen and Van den Broeck modified the production function to allow for the presence of technical inefficiencies captured by a one-sided error term. The original specification involved a production function for cross-sectional data with an error term with two components: one to account for random effects and another to account for technical inefficiency. The model specification has been extended to accommodate different distributional assumptions for the inefficiency term, for panel data, and for time-varying technical efficiencies. This standard neoclassical production function is re-labeled a stochastic production frontier and following Battese and Coelli (1995) is written:

(1) $\ln Y_{it} = f(x_{it}, t; \beta) + v_{it} - u_{it} \quad i = 1, \ldots, I, \ t = 1, \ldots, T$

where Y_{it} is output of the *i*-th country in time period *t*, x_{it} is an *Nx1* vector of the logarithm of inputs for the *i*-th country in time period *t*, β is a vector of unknown parameters, v_{it} are random variables which are assumed to be iid $N(0, \sigma_v^2)$, and independent of u_{it}, and u_{it} is a non-negative random variable distributed iid $N(\eta, \sigma_u^2)$, associated with technical inefficiency across production units (or individual production units effects.) In our case, it accounts for heterogeneity across countries that can cause departures from maximum potential output.

We use this production frontier to break down the growth rate of aggregate output into contribution from the growth of inputs versus productivity change:

(2) $\dot{Y}_{it} = \sum_n \varepsilon_{itn} \dot{x}_{itn} + \dot{TFP}_{it}$

where a dot over a variable indicates its rate of change, and ε_{itn} is the production elasticity of input *n*, for country *i* in year *t*, $\varepsilon_n = \frac{\partial f(x,t,\beta)}{\partial x_n}$. In turn, TFP growth can be decomposed as (dropping the *it* subscripts for simplicity):

(3) $\dot{TFP} = TC + EC$

where a shift of the production frontier representing technical change is $TC = \frac{\partial f(x,t;\beta)}{\partial t}$,

and technical efficiency change, EC, is the rate at which a country moves toward or away from the production frontier, which itself may be shifting through time.

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 question, the identification of institutional and political factors that underlie differential productivity growth performance across countries in SSA. Technical inefficiency is captured in equation (1) by the non-negative random variable u. The ratio of observed output for the i-th country relative to its potential output when the individual country effects are zero, is used to define the technical efficiency of the i-th country in period t, $TE_{it} = \frac{Y_{it}}{\exp[f(x_{it};\beta)+v]} = \exp(-u_{it})$. This measure of technical efficiency takes on values of 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 change in *TE* between two periods is *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 follow Battese and Coelli and 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. The technical inefficiency effect u_{it} for the i-th country in the t-th period has a truncated iid $N(\eta_{it}, \sigma_u^{2})$ distribution, where the mean is

(4) $$\eta_{it} = h_{it}\delta,$$

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

For implementation, the production function in (1) is approximated with a specific functional form that imposes minimal *a priori* assumptions, a flexible form. Two types of approximation have been used in the literature, Taylor series and Fourier series, with the first being more common than the last. Gallant (1981, 1982) argues convincingly for the superiority of the Fourier approximation in economic applications. He shows that the use of fixed parameters flexible functional forms based on Taylor's expansion, such as the Translog, generalized Leontief, or the Box-Cox, leads to statistically valid inferences only if the true technology is a member of the parametric class considered, otherwise the inference is biased.[1] If the idea is to test an economic proposition rather than an obscure consequence of specification error then a specification that allows consideration of which errors in the approximation of the true technology by a flexible form are important and which can be neglected is preferable. Gallant indicates that a measure of distance which is large under *relevant* approximation errors and which neglects others is the Sobolev norm.[2] He finds that a logarithmic version of the Fourier flexible form has the property of minimizing distance in Sobolev space.[3] This is particularly important in our study because this type of approximation has been shown by El Badawi, Gallant, and Souza (1982) to approximate not only the function itself but its derivatives and we are interested in estimating technical change as consistently as possible minimizing the augmenting hypothesis induced by model specification. We follow Gallant and choose the Fourier flexible form to approximate the production technology, a semi-nonparametric form, which combines a standard linear and quadratic form with a non-parametric Fourier series. This form has not been used before in primal space to approximate a production function or in the context of a production frontier. We write it:

$$(5) \quad f_k(x) = u_0 + bx + \frac{1}{2}x'Cx + \sum_{\alpha=1}^{A}\left\{u_{o\alpha} + 2\sum_{j=1}^{J}\left[m_{j\alpha}\cos(jk_{\alpha}^{'}z) + n_{j\alpha}\sin(jk_{\alpha}^{'}z)\right]\right\}$$

where x is a *Nx1* vector of variables, b is a *Nx1* vector of coefficients, C is a *NxN* symmetric matrix of coefficients, z is a *Nx1* vector of rescaled values of x, $m_{j\alpha}$ and $n_{j\alpha}$ are coefficients, $k_{\alpha}^{'} = [k_{x_1}, k_{x_2}, ..., k_{x_N}]$ are multi-indices, *1xN* elementary vectors representing the partial derivatives of the Fourier production function with each set producing a particular Fourier series expansion. Details on the construction of this form are in Appendix I.

The first derivatives of (5) with respect to the log of inputs would give the production elasticities, while the derivative with respect to the proxy variable for technological change is TC. This latter concept is the one of interest. These derivatives are combinations of parameters and variables that can be evaluated after estimation. Along with the estimates for EC obtained from fitting equation (4) we would have all components needed to evaluate TFP growth according to equation (3).

Data

Panel data on output and conventional agricultural inputs (land, labor, fertilizer, tractors and animals) for 41 SSA countries for 1961-1999, are collected from the FAOSTAT website. These data have been used in nearly every previous study of agricultural productivity in SSA countries. Table 1 presents the summary statistics for the data set.

Agricultural output is expressed as the quantity of agricultural production in millions of 1989-1991 "international dollars". We refer to land, labor, livestock, machinery and fertilizer as traditional inputs. Agricultural land is measured as the sum of arable land and permanent crops in thousand 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 in thousands. 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 consist of 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 and 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. Two types of efficiency changing variables are considered in this analysis, those that allow for *qualitative* input differences and those that will capture differences in the *institutional and socio-political* environment across countries. In addition a dummy variable is included for Ethiopia for years after the secession of Eritrea in 1992. As there is no data for Eritrea prior to this date, we merge the data for both countries for the period 1992-1999 and call it Ethiopia.

Although ideally in the first set we would like to have variables that would adjust all inputs for their quality, data availability restricts us to three: land quality, illiteracy, and droughts. We expect that higher quality of land would induce higher productivity while droughts and a more illiterate population would be consistent with lower rates of productivity growth. In this set we include the following. a) Labor quality proxied by adult illiteracy rate taken from the World Development Indicators 2001 (World Bank.) b) Both percentage of irrigated land and drought are used as proxies for land quality. The percentage of irrigated land was calculated as the ratio of irrigated 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. A dummy variable for drought is assigned to one for an occurrence of drought according to either the Keck and Dinar study or data in the African Development Indicators 2002.

The second set of variables, also referred as institutional variables, is chosen to potentially capture the socio-political climate. The variables chosen, given data availability, areas follows. a) Colonial heritage because of its persistent influence in political, economic, cultural, military, financial and religious structure. We utilize dummy variables for former British, French and Portuguese colonies (versus Belgian and U.S. as reference), collected from Encyclopedia Britannica. b) Independence, the number of years since independence, collected from the Central Intelligence Agency World Factbook. c) Armed conflict, we constructed three dummy variables to indicate minor conflict, intermediate conflict and war (contrasted with no conflict.) These variables were created based on data from Gleditsch et. al. d) Political rights and civil liberties, two dummy variables to represent the Freedom House index of political rights and civil liberties that categorize countries as free or partly free (contrasted with not free), from 1972 to 1999. We expect that war and violence will depress productivity growth while we have no priors for the other variables.

Estimation

We choose to approximate the production frontier in equation (1) with a Fourier flexible form as in equation (5), a linear combination of trigonometric and polynomial terms that have the capability of representing exactly any well-behaved multivariate function and its derivatives. There are a number of studies that compare the performance of Taylor-type approximation (also referred to as locally flexible) to Fourier-type approximations (also referred to as globally flexible) in economic applications. Gallant (1981) noticed that the Translog power curve only increases locally while the Fourier form gains full power as departures from the null case become extreme. Wohlgenant compared the Fourier with the Translog and generalized Leontief functional forms in a demand context, and showed the superiority of the Fourier. Mitchell and Onvural and Huang and Wang have found bias in the Translog cost function estimates.[4]

One of the issues of importance (and debate) when choosing a Fourier form is the choice of *K*, or the numbers of Fourier terms to include in the approximation. It has been shown by Gallant, Chalfant, Mitchell and Onvural, Terrell and Dashti, Flesissig, Kastens and Terrell and others that there is an important bias-stability trade-off in choosing the number of terms. This trade-off could be very important in cross section applications where the observations are countries of different sizes and when there is likely to be measurement errors, like in the data set we use.

Gallant suggests that this decision depends on whether the objective is that of hypothesis testing or estimation. He indicates that if testing hypotheses is the objective then a large *K* would be appropriate as it reduces the probability of spurious rejection by reducing prediction bias and by reducing the power of the test by inflating the variance of the test statistic. Ideally pretesting should be avoided. If the objective is estimation, as in this paper, then the situation changes and there is less reluctance to use pretesting. He advises the use of " The conventional approach to these problems…" [5] by which he means the determination of a model by downward selection or upward selection using an appropriate *t*-test, *F*-test, or *Chi*-square-test and a stopping rule to delete one or more terms. As will be seen below we proceed by downward selection.

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.[6] This paper does so using 1599 observations for 41 countries and 39 years. Denote with $i = 1,\ldots, 41$ the countries, and with j and $k = 1,\ldots, 5$ the inputs x_{ijt} and x_{ikt} at each time period $t = 1, \ldots, 39$. Each observation of inputs and outputs is strictly positive. Under symmetry, the Fourier production frontier we estimate is:

$$(6) \quad \ln Y_{it} = u_0 + \sum_{j=1}^{5} b_j x_{ijt} + \frac{1}{2}\sum_{j=1}^{5} c_{jj} x_{jj}^2 + \sum_{j=1}^{5}\sum_{k>j}^{5} c_{jk} x_{ijt} x_{ikt} + b_t t + \frac{1}{2} b_{tt} t^2 + \sum_{j=1}^{5} b_{jt} x_{ijt} t$$

$$+[m_t \cos(z_t) + n_t \sin(z_t)] + \sum_{j=1}^{5}\sum_{k>j}^{5} [m_{jk} \cos(z_{ijt} - z_{ikt}) + n_{jk} \sin(z_{ijt} - z_{ikt})]$$

$$+\sum_{j=1}^{5}\sum_{k>j}^{5} [m_{jk1} \cos(z_{ijt} - z_{ikt} - z_t) + n_{jk1} \sin(z_{ijt} - z_{ikt} - z_t)]$$

$$+\sum_{j=1}^{5}\sum_{k>j}^{5} [m_{jk2} \cos(z_{ijt} - z_{ikt} + z_t) + n_{jk2} \sin(z_{ijt} - z_{ikt} + z_t)]$$

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

where *Y* is agricultural output; *x* is a vector of logarithms of inputs (land, labor, livestock, machinery, and fertilizer); *t* is time from 1 to 39, a proxy for technical change; the *z* is a vector of rescaled *x*'s and *t*; *k* is a "multi-index" vector of integers that creates an index of the z_i's (described in more detail in Appendix I); *b, c, m, n* are parameters to be estimated, *u* is the one sided error assumed truncated at zero and distributed iid $N(\eta, \sigma_U^2)$ 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 the Fourier frontier is augmented by adding a random error *v*, an iid $N(0, \sigma_v^2)$ that is independent of *u*. This is a stochastic Fourier frontier.

As stated before, the technical inefficiency term is a function of input quality proxies and institutional and socio-political variables and is specified for simultaneous estimation with (6) as:

$$(7) \qquad u_{it} = h_{it}\delta + \xi_{it}$$

with random variable ξ_{it} sharing the distributional characteristics of random variable u_{it}. Due to the availability of freedom data only from 1972 onward, the "base" model for 1961-99 includes all the efficiency-changing variables except the freedom variables, while the "freedom" model includes these variables.

Simultaneous maximum-likelihood estimation of 88 parameters in equation (6), 60 of which are Fourier terms, and thirteen in equation (7) for the base model (fifteen in equation (7) for the freedom model,)[7] is performed using the FRONTIER 4.1 program developed by Coelli (1996a.) These estimates are the benchmark used to perform the tests below and are referred to as the "full" model .[8] Parameter estimates can be obtained from the authors.

Three sets of test are performed. The criteria used are a combination of statistical fit guided by the appropriate likelihood ratio tests, and consistency with theoretical production theory properties. A first set of tests looks at technical change captured by a time trend. Tests for the presence of technical change and for Hicks-neutrality are performed by estimating equations (6) and (7), setting the appropriate coefficients to zero and comparing its likelihood with that of the full model described in the paragraph above. Results of these tests indicate that there has been technical change and it is not Hicks-neutral.[9]

A second set of tests considers the presence of efficiency changing terms. Three tests are performed for both the base and the freedom models. The first one tests the null of no technical inefficiency (or the appropriateness of the one-sided error specification), the second test the null hypothesis of no country specific factors influencing technical inefficiency by setting the parameter γ (a ratio of standard errors) and all parameters in equation (7) to zero, the third tests the null that the parameters for subgroups[10] of the efficiency changing variables are zero. All tests reject the respective null hypotheses indicating that a frontier model that includes all the country specific variables in the efficiency term is appropriate.[11]

The third set of tests performed regards the functional form. It is an important set of tests given the trade-off between bias and stability mentioned before as the number of Fourier terms included increases. Six nested functional forms are tested for both models in accordance with the principle of downward selection. The functional forms included that are nested within the model of equation (6) are: a 68 parameter Fourier form with 40 Fourier terms; a 48 parameter Fourier form with 20 Fourier terms; a 30 parameter Fourier form with 2 Fourier terms; a 28 parameter Translog form, and a 7 parameter Cobb-Douglas form.[12] Equation (7) includes the same twelve variables in all "base" models, and the same fourteen variables in all "freedom" models. Likelihood ratio tests of each form against the higher order forms are performed (a total of 15 each) for the base and the freedom models and the lower order forms are rejected in each case. Two implications follow. First, the agricultural production function does not have the Cobb-Douglas or Translog form. This indicates the Fourier series terms are significant additions to the model. Second, the full model of equations (6) and (7) produces estimates of the production function and its derivatives (therefore of technical change) with the least amount of approximation error.

It is at this point that we introduced a second criterion to evaluate the model, that of consistency of the estimates with the properties of production theory. We obtain estimates of production elasticities and technical change for each of the models tested above and we evaluate monotonicity ex-post. Of all the forms, the Cobb-Douglas is the only one to estimate positive production elasticities showing no violations of monotonicity. As the functional form grows more complicated, the violations of monotonicity increase. This suggests that we might be adding instability to the estimates by including "too many" trigonometric terms that capture small fluctuations in the data. We can call this a typical situation of bias-instability trade-offs. While statistical tests are indicating that to minimize specification bias the more flexible form should be chosen (Fourier form with 88 parameters), consistency with production theory leads us to choose the least flexible form (Cobb-Douglas form with 7 parameters.) Estimates of these elasticities at the sample mean of the data along with percentage violations of monotonicity over all observations are presented in Appendix II. While the number of violations is high, this is a common finding in most panel studies of this type. For SSA agriculture, the studies by Pardey el al. and by Thirtle et al reports report 100 percent monotonicity violations.

Our results are consistent with the conclusion of Fleissig, Kastens, and Terrel who evaluated simulated data with three semi-nonparametric functions including the Fourier flexible form, and found that for data sets with severe measurement error, functional forms with higher order expansions failed to adequately approximate the true technology, resulting in violations of concavity and poor elasticity estimates.[13] When measurement error increases, it is preferable to decrease the order of the expansion. Earlier, Chalfant had noticed that in estimating a cost function for US agriculture, the Fourier flexible form failed to satisfy the curvature and monotonicity restrictions in three-fourths of the sample period. He attributed it to the use of aggregate data. Terrell and Dashti also indicate that concavity and monotonicity violations appear to be a serious problem for the Translog and Fourier frontiers they fit. In addition they pointed out that measurement of technical (in)efficiency is quite sensitive to the choice of functional form used. They compared a Cobb-Douglas, a Translog, and a Fourier flexible form and found increased efficiency as the model specification moves to a more flexible approximation.

Given the poor quality of the data set used in this study, reducing the order of expansion might help reduce the violations of economic theory but at the expense of approximation accuracy. We do not know of any formal method of weighting these two objectives so we proceed in an *ad-hoc* manner and choose the simplest semi-nonparametric form tested after imposing symmetry:

(8) $$\ln Y_{it} = u_0 + \sum_{j=1}^{5} b_j x_{ijt} + \frac{1}{2}\sum_{j=1}^{5} c_{jj} x_{jj}^2 + \sum_{j=1}^{5}\sum_{k>j}^{5} c_{jk} x_{ijt} x_{ikt} + b_t t + \frac{1}{2} b_{tt} t^2 + \sum_{j=1}^{5} b_{jt} x_{ijt} t$$

$$+ [m_t \cos(z_t) + n_t \sin(z_t)] - u_{it} + v_{it}$$

with inefficiency specified as in (7). This is the model we use to approximate the production function (1.) Given our interest in estimating technical change, we use the nonparametric Fourier terms to reduce the impact of specification bias in the approximation to technical change. The first derivative of (8) with respect to t gives the equation we use to evaluate TC:

$$\text{(9)} \qquad \text{TC}_{it} = b_t + b_{tt}t + \sum_{j=1}^{5} b_{jt}x_{ijt}t + [m_t \cos(z_t) - n_t \sin(z_t)]\lambda$$

where λ is a common scaling factor (see Appendix I.)

We simultaneously fit equations (7) and (8) that under the assumption of symmetry has 28 Translog parameters, 2 Fourier terms that approximate technical change, and thirteen inefficiency parameters for the base model (fifteen for the freedom model.) In the base model, twenty-one out of forty-three parameters are significantly different from zero at the 95% confidence level while twenty-five out of forty-five are significant for the freedom model (see Table 1.) Then we use these parameters along with observations in equation (9) to evaluate technical change.

It is not very informative to discuss the average rate of technical change far all countries and years as grand averages "hide" information. We find it more informative to look at the evolution of the annual average TC for the base and freedom models, evaluated according to equation (9.)

From the evolution of TC shown in Figure 1 there are two obvious conclusions. First, the Fourier terms have shaped technical change. Second, the rate of technical change for the whole region was negative in the 60's and 70's and turned positive during the 80's and 90's.

The other concept of interest is efficiency change, as reflected in the estimates of δ in equation (7). We can see in Table 1 that the effect of illiteracy is insignificant, irrigation decreases inefficiency and drought increases it. This implies that the evolution of productivity growth across countries is significantly affected by the availability of irrigation and the presence of droughts and that these variables can explain some of the differential performance of these countries. While Pardey *et al* found illiteracy significant, Thirtle *et al* found it insignificant. The drought and irrigation results support the findings in the studies by Block, Frisvold and Ingram, Thirtle *et al*, and Pardey *et al*. With respect to the institutional variables, accounting for colonial history seems to be important, as well as the respect of political rights and civil liberties. The estimates indicate that, *ceteris paribus*, being an ex-French colony decreases inefficiency relative to the comparison group (ex-Belgium, ex-U.S. protectorate and Ethiopia.) while the opposite is true for former U.K. and former Portuguese colonies, with the latter performing worse. This result is consistent with the information given in the next section showing that former U.K. colonies, on average, outperformed the rest as it indicates that, after accounting for other institutional and resource quality differences, there is not much left to be explained by the colonial dummy variables. The coefficients associated with the enjoyment of political rights and civil liberties indicate that the more these rights are respected, the more efficient is the country's agriculture, result consistent with Pardey *et al.* The variables indicating years since independence and the presence of conflict are not individually significant. They are significant as a group though as the tests for the subgroups of efficiency changing variables indicated.[14]

Agricultural Productivity Performance in SSA

Our objectives have been to obtain measures of SSA agricultural productivity covering the most complete set of countries and years to date, and to explore the potential role of institutional variables in understanding differences between the performances of individual countries. The pooled frontier production function of the previous section provides the basis for addressing these objectives. We find that the area achieved average productivity gains of 0.83%[15] per year over the four decades (all cross-country averages reported here are weighted by current share of SSA agricultural output.) This is consistent with the 0.49% estimated by FAO for approximately the same period and countries. It is quite different from the -.086% estimated by Suhariyanto, *et al*., although the decade-by-decade time path found in that study is nonetheless quite similar to ours.

Average gains were positive for each decade except the 1970's, when average productivity declined at the rate of 0.3% per year (Figure 2, Table 3) We find no readily evident causes for the failure during the 1970's. Drought was not unusually prevalent during that decade (drought was very widespread during 1982-84, and did appear to produce negative productivity gains during those years.) Wars and civil disturbances do not appear to be more severe during those years, either. Since 1985, average productivity gains for SSA agriculture have been quite strong, averaging 1.90% per year, a level comparable to those in industrialized countries. The "recovery" first noted by Block for the years 1983-88 seems to have persisted, despite his pessimism about that possibility.

Colonial heritage

In Table 4 we report the four-decade productivity growth rates for the individual countries. We have grouped the countries according to their colonial heritage, and it is evident that there are very substantial differences between these groups. The four former Portuguese colonies had the poorest performance, averaging -0.26% per year, with Liberia (former U.S. protectorate) about the same at -0.25%, the three former Belgian colonies next poorest with -0.17% per year. The14 former French colonies came next with a positive average productivity gain of 0.52%, Ethiopia with an average productivity gain of 0.76%, while the 18 former British colonies performed the best with an average 1.08% productivity gain per year.

Figure 3 charts these differences by colonial heritage groupings. It shows that trends, as well as levels, differ among the groups. The three Belgian colonies have done badly during the 90's because of armed conflicts, resulting in a marked downward trend in the rate of productivity change over the four decades. The UK group showed not only the highest average level of productivity gains, but one of the highest growth rates in TFP gains, as well. The four ex-Portuguese colonies have had the strongest upward trend since the disastrous 1970's, achieving gains approximately equal to the ex-French colonies during the 1990's.

These average productivity rankings differ from those suggested by the efficiency coefficients in the frontier analysis, as mentioned earlier. Those coefficients indicated that the former French colonies had the highest base efficiency of any group, significantly higher than the Belgian (Recall that negative coefficients in Table 2 indicate higher efficiency.) The dummy variable coefficient for former UK colonies indicates a base efficiency 0.23 % lower than "Other", and that for former Portuguese colonies indicates a base efficiency .09% lower (both significant.) But the dummy variables for colonial history are only one of the efficiency-changing variables, and because they do not change through time, they do not affect changes in productivity through time. As also noted by Englebert (2000), while the dummy variable for former UK colonies indicates relatively low base technical efficiency, those countries have experienced more favorable trends in efficiency-changing variables, which raises their rate of productivity gain to a level that exceeds other groups, as was shown in Table 4.

In Table 5 we report the number of country-years in which colony groupings experienced drought, conflicts and respect for political rights and civil liberties. Recall that we utilize Gleditsch's characterization of a country being in a minor conflict, a major conflict or a war for a given year, and Freedom House's characterization of a country being free (enjoying a substantial measure of political rights and civil liberties), partly free (a lesser measure), or not free (a minimal measure) in a given year. Differences across country groupings will contribute to differences in average levels of technical efficiency according to the coefficients in Table 2. These differences in average level will cause the *levels* of TFP to differ, but it is the change in TFP through time that interests us, and therefore the changes in efficiency changing variables. The average levels are revealing, however. First, the incidence of drought in the various groups didn't differ much from the SSA average of 22% of years, although the Belgian group in equatorial Africa suffered about half as much drought as others. But as for a history of conflicts, the former Portuguese colonies experienced conflicts nearly half of the years on average, compared to an average of only 12% and 18% of the time in former French and UK colonies, respectively. The former Belgian colonies experience war only 23% of the time, but virtually all of this occurred in the 1990's, resulting in a sharp reduction of TFP gains during that period. As for "freedom", the degree of political and civil rights, the Belgian group never scored more than "partly free", and that only 13% of the time. By comparison, the UK group scored at the level of free or partly free 63% of the time. Three times as much conflict and one-fifth as much respect for political and civil rights can certainly be expected to reduce average productivity levels in these groups relative to that experienced by former UK colonies, the result of which we saw in Table 4.

We note that in the British group, Nigeria and South Africa not only posted the highest productivity gains, 1.64% per year for each, but they are also the largest countries, constituting an average of 17% and 13% of SSA agricultural output over this period, respectively. Thus they are significant contributors to the relatively high productivity rates for the UK group. But the remaining 16 British countries nonetheless averaged a positive 0.32% productivity gain per year, with only six[16] experiencing overall deterioration in productivity.

Years since independence

One issue related to the time of independence is the path of productivity growth after independence. The regression results in Table 2 indicated a slightly positive (but statistically insignificant) trend in technical efficiency after independence. To picture the path of productivity after independence, we plot in Figure 4 the average rate of productivity growth experienced by all countries in a given year since independence (average is in this case a simple average across countries.) The path is quite erratic, though inspection and the quadratic trend line offer some evidence that productivity tends to be stagnant or decreasing during the first 12 years of independence, then tending to increase thereafter.

Alternatively, in Table 6 we group the countries according to the years since independence and unveil the following associations with the average rate of productivity growth over the period. Again we notice that there is a positive relation between years since independence and productivity growth, except for the group of Ethiopia and Liberia that by 1999 had been independent for more than 100 years and Zimbabwe and Namibia who are the only countries in the sample that have attained independence within the 20 years before 1999. Second, we notice that twenty-nine out of forty-one countries had been independent for approximately forty years by 1999, representing 63 percent of agricultural production of SSA and having a weighted average productivity growth of 0.58 percent. Thirteen former British colonies, thirteen former French colonies, and 3 former Belgium colonies attained independence in the 1960's. We notice that Nigeria, with its relatively big share of production and its average TFP growth of 1.6 percent, is one of the ex-British colonies in this group and heavily weights in the average. We take a more detailed look at the countries that gained independence in the 1960's purging Nigeria's influence and found in Table 6 that their weighted average productivity growth dropped to 0.20 percent while they represent 47 percent of agricultural production in SSA. The positive association we noticed is even more pronounced. Figure 5 groups them by colonial influence and shows that ex-French colonies (0.49 percent TFP growth) have outperformed ex-British colonies when Nigeria is not included (0.22 percent TFP growth) and certainly they have both outperformed ex-Belgium colonies (-0.17 percent TFP growth.)

Political Rights and Civil Liberties

As previously mentioned, we have acquired two indexes of political freedom that Freedom House has published for these and other countries, but they became available only beginning in 1972. Each year Freedom House has rated each country as "not free", "partly free", or "free", based on a series of checklists relating to political rights and civil liberties. In Table 5 we have reported the fraction of years in which the various countries were rated free or partly free. To obtain an econometric estimate of the effect of political freedom, we re-estimated the Fourier form base model for the 1973-1999 period, including one dummy variable for "partly free" and another for "free." The results of this regression were in all respects very similar to those of the base model for 1962-1999. The correlation between country average TFP measures predicted by the two models was 0.77, and that between aggregated annual average TFP measures was 0.98.

The coefficient of the "Partly Free" dummy was –0.26, and that of the "Free" dummy variable was –0.39, both highly significant. The interpretation is straightforward – in a year in which a country was rated "Partly free", the country is predicted to be 26% more technically efficient than when not free. In a year in which it was rated "Free", it is predicted to be 39% more efficient. From these results, it is reasonable to infer that average differences in political freedom between former Portuguese and former UK colonies, for example, would result in a difference in technical efficiency of about 10%, and therefore an average productivity difference of the same amount. As discussed in the previous section, however, it is change in freedom that would impact productivity gains or losses, so it appears that there is ample opportunity for all of these countries to improve their agricultural efficiency and productivity by respecting political rights and civil liberties.

Our results indicating the effect of colonial heritage on agricultural productivity growth corroborate previous findings by Bertocchi and Canova (2002), Grier (1999), Landes (1998) and North (1998), all of which found former British colonies to achieve higher per capita GDP growth rates than former French or Portuguese colonies. The explanations they advance for these differences are that institutions such as property rights, political freedom, free markets, etc., do matter in determining the vigor of economic growth. In our study, it is clear that respect for political and civil rights and absence of conflict are two of the institutional characteristics that contribute to the differences between the colonial groups with regard to agricultural productivity performance.

Conclusions

In this study of agricultural productivity in 41 Sub-Saharan Africa countries, we have found that the region made some progress in the 1960's, suffered a regression in productivity during the 1970's, but after the mid-1980's recovered to achieve a reasonably robust rate of productivity improvement through the end of the century. The over-all average rate of productivity growth for the four decades was estimated at 0.8% per year. The general nature of these results is consistent with several other studies of SSA agricultural productivity published since 1995, which should not be too surprising since the basic data sources are virtually the same. However, our analytical approach was quite different from any other study, and this provides some confidence in the robustness of the estimates, particularly useful in the case of SSA agriculture given the limitations in the quantity and quality of data needed for the purpose.

We estimated TFP gain or loss for each country in each year as the sum of predicted change in the production frontier in that vicinity plus predicted change in technical efficiency for that country and year. We used the Battese-Coelli approach to estimate the efficiency effects of institutional and other efficiency-changing variables, with the production frontier specified as Gallant's Fourier flexible form. We found, as have others, that the use of a fully-parameterized Fourier flexible form (60 Fourier parameters in our case) could be justified by goodness-of-fit criteria, but created violations of the required monotonicity property. Balancing these two criteria subjectively, we chose a very abbreviated Fourier form with only sine and cosine Fourier expansions of the time trend, which allowed us to retain flexibility in estimating the time path of technical change over the four-decade period.

A primary objective of the study was to examine the relationship between growth in productivity and institutional factors, following a number of recent studies showing that GDP growth rates are strongly affected by those factors. We found that 19 ex-British colonies experienced the highest TFP growth rates of colonial groupings, with three ex-Belgian colonies and Liberia the worst performers (their TFP diminished over the period), and 14 ex-French and four ex-Portuguese colonies having intermediate performance levels. These differences were determined in significant measure by the estimated effects of wars and civil conflicts and differences in respect for political and civil liberties as measured by Freedom House indexes. These results indicate that institutional factors are important determinants of agricultural productivity growth, as well as per capita GDP growth as established in other recent studies.

We have noted in other studies that TFP growth is not synonymous with increases in well-being of the population, and that point is certainly relevant to this research. There are approximately 200 million undernourished Africans, a 15 percent increase since the early 1990's and a doubling since the late 1960's. There are 25 million individuals infected with HIV/AIDS, approximately 14 million have died from it, and average life expectancy has declined from 62 to 47 years old. While TFP growth rates of 0.8% or 1.9% might be a necessary condition for welfare increases, they are not a sufficient one as these figures for malnutrition and life expectancy in SSA show.

Figure 1. Technical change in SSA during 1961-1999.

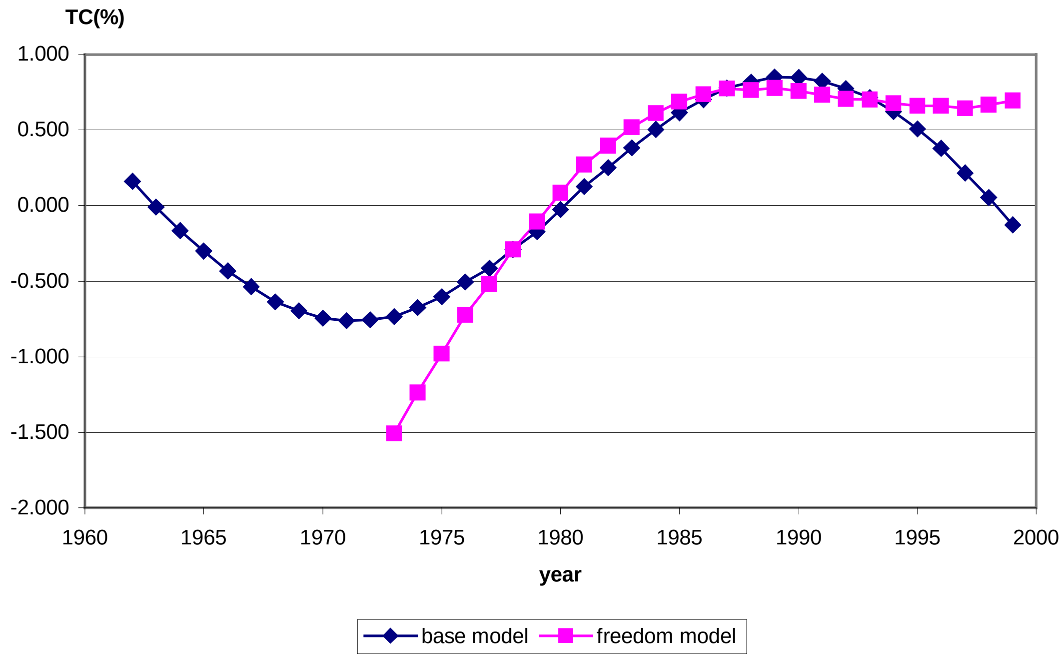

Figure 2. Annual average TFP change in 41 SSA countries.

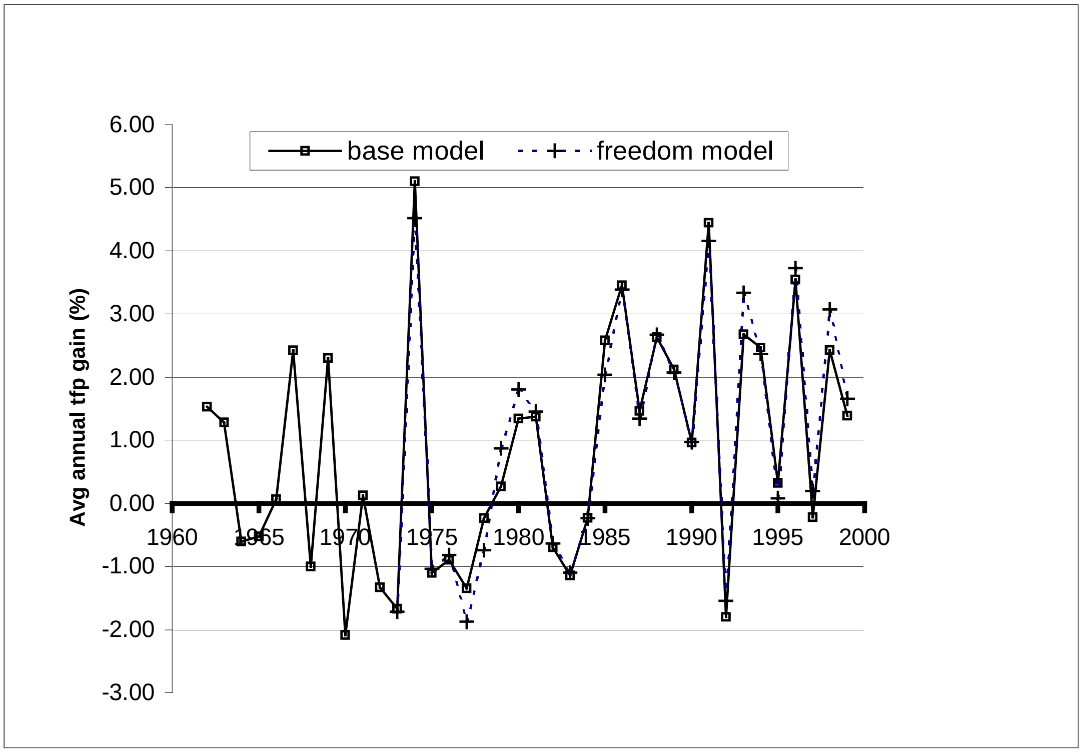

Figure 3. Decade Average TFP by Colonial Heritage Groups

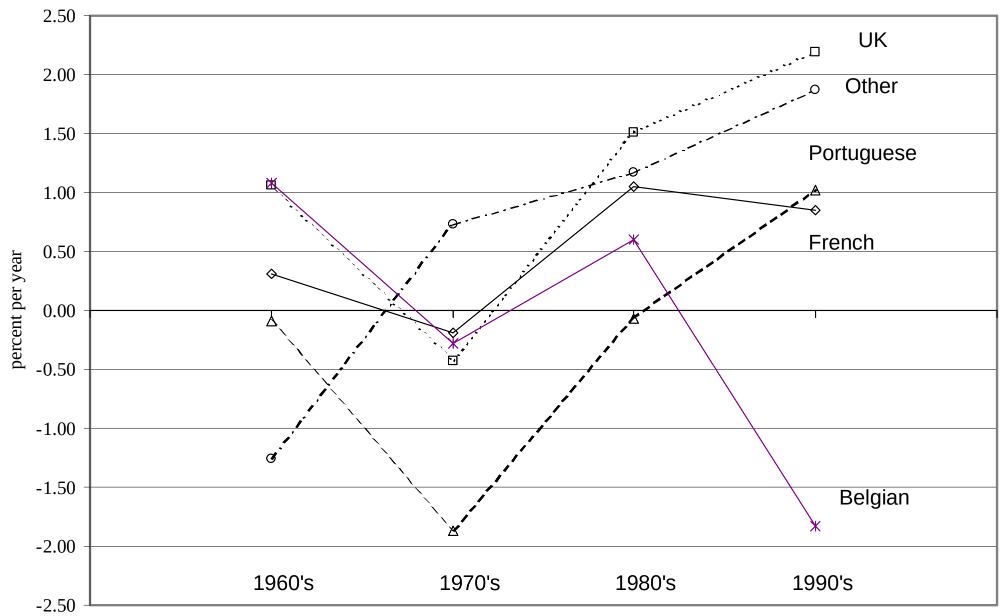

Figure 4. Average annual TFP increase by Years Since Independence

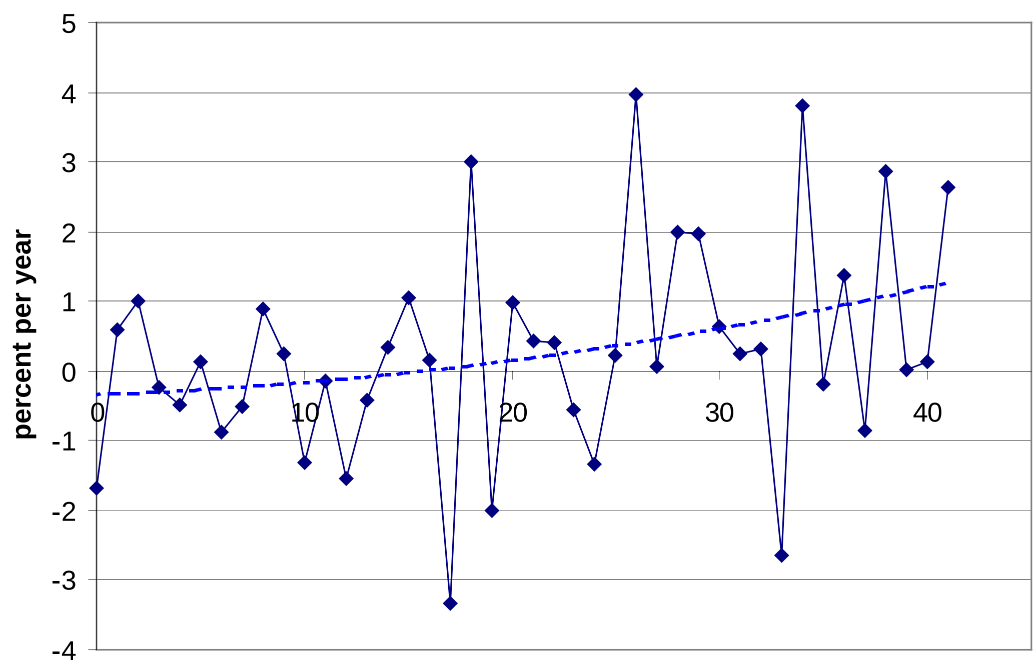

Figure 5. TFP Ex-Colonies Independent in 1960's
(without Nigeria)

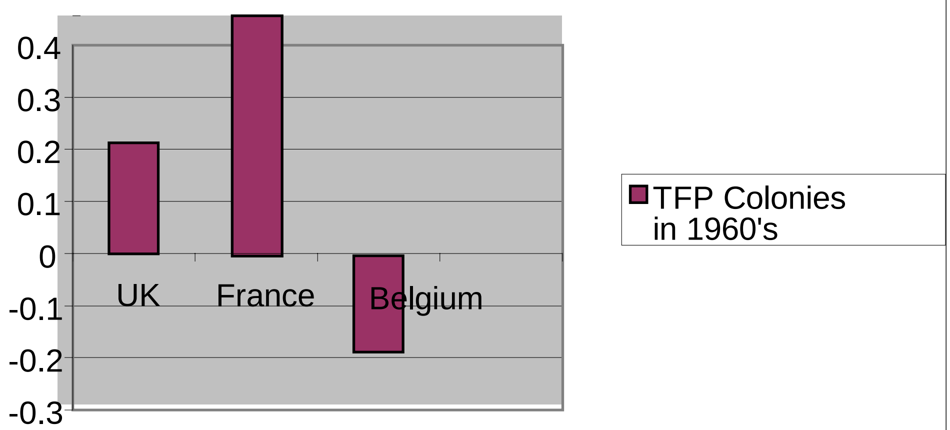

Table 1. Summary statistics for the variables in the data set.

variable	unit	mean	minimum	maximum	standard dev.
conventional inputs and output					
output	millions of international dollars	1243	5.40	17433	1829
cropland	1,000 hectares	3722	40	32909	5449
labor	1,000 persons	3076	34	23867	3721
livestock	number of cattle equivalent	4493550	22182	43453184	7017772
machinery	number of tractors	6256	2	175557	23055
fertilizer	metric tons	37313	5	1232886	121439
input quality					
drought	1=drought, 0 otherwise	0.22	0	1	0.41
irrigation	% of irrigated land	0.91	0.0	17.7	2.30
adult illiteracy	% of illiterates	61.78	12.0	96.8	21.69
institutional environment					
independence	years after independence	21.38	0	152	23.00
Former UK colony	dummy	0.44	0	1	0.50
Former French colony	dummy	0.34	0	1	0.47
Former Portuguese colony	dummy	0.10	0	1	0.30
conflicts and wars					
minor conflicts	dummy	0.07	0	1	0.26
intermediate conflicts	dummy	0.04	0	1	0.20
war	dummy	0.10	0	1	0.30
political freedom					
free	dummy	0.11	0	1	0.31
partlyfree	dummy	0.34	0	1	0.48

Table 2. Parameter estimates for stochastic Fourier frontier model.

	base model		freedom model	
Parameter	estimate	t-ratio	estimate	t-ratio
intercept	-3.06	-5.57	-5.64	-5.64
translog				
b1	-0.44	-4.14	-0.74	-6.13
b2	1.11	6.81	0.89	3.97
b3	0.2	1.7	0.85	3.66
b4	-0.19	-3.24	-0.20	-2.42
b5	0.72	18.21	0.79	16.12
b11	0.1	3.34	0.17	4.51
b12	0.04	0.81	-0.06	-1.08
b13	-0.1	-6.81	-0.11	-5.87
b14	0.05	3.84	0.06	4.18
b15	-0.02	-1.22	-0.03	-1.71
b22	-0.02	-0.75	-0.03	-0.75
b23	0.02	0.75	0.10	2.26
b24	-0.05	-4.19	-0.07	-4.07
b25	-0.03	-3.04	-0.02	-1.74
b33	0.02	3	-0.01	-0.79
b34	0.03	4.13	0.03	3.07
b35	-0.06	-12.25	-0.07	-9.86
b44	0.01	3.6	0.02	4.26
b45	-0.03	-6.95	-0.03	-5.03
b55	0.04	14.55	0.05	13.80
b1t	0.01	5.09	0.01	4.81
b2t	-0.01	-5.52	-0.01	-4.78
b3t	-0.0001	-0.18	0.0004	0.38
b4t	0.0001	0.21	-0.002	-2.47
b5t	0.001	1.73	0.001	2.00
bt	0.001	0.07	-0.04	-0.76
btt	-0.0001	-0.47	0.001	0.64
Fourier				
mt	0.06	1.91	0.02	0.20
nt	-0.002	-0.13	-0.05	-0.69

parameter	estimate	t-ratio	estimate	t-ratio
Efficiency intercept	0.27	1.84	-0.28	-0.85
Input quality				
Irrigation	-0.22	-24.48	-0.23	-20.61
Drought	0.15	3.26	0.12	2.43
Illiteracy	0.0005	0.63	-0.0005	-0.42
Institutional environment				
Independence	-0.002	-1.39	-0.001	-0.86
UK	0.23	2.19	0.73	2.64
France	-0.22	-2.13	0.17	0.62
Portugal	0.75	6.29	1.25	4.78
Minor conflicts	-0.11	-1.3	0.04	0.39
Intermediate conflicts	-0.19	-1.96	-0.04	-0.34
War	-0.05	-0.73	0.13	1.49
Free	-	-	-0.39	-4.66
Partly free	-	-	-0.26	-4.14
Ethiopia	-0.99	-1.52	-2.75	-1.92

Table 3 Average annual TFP change in SSA agriculture, by decade	
Decade	Average TFP change -----% per year----
1960's	0.68
1970's	-0.32
1980's	1.29
1990's	1.62
1961-1999	0.83

Table 4. Average 1962-99 TFP gains by country

Former Belgian colonies:		**Former British colonies:**	
Burundi	-0.99	Botswana	-0.06
Dem Rep of Congo (Zaire)	-0.12	Gambia	-1.56
Rwanda	-0.01	Ghana	0.34
average	***-0.17***	Kenya	0.68
Former French colonies		Lesotho	-0.75
Benin	0.78	Malawi	-0.06
Burkina Faso	0.58	Mauritius	0.27
Cameroon	0.87	Namibia	0.48
Central African	0.95	Nigeria	1.59
Chad	0.34	Sierra Leone	0.11
Congo	-0.76	Somalia	-0.64
Côte d'Ivoire	0.57	South Africa	1.64
Gabon	0.13	Sudan	0.66
Guinea	-0.41	Swaziland	1.11
Madagascar	0.04	Tanzania	0.75
Mali	0.51	Uganda	-0.36
Niger	-0.43	Zambia	0.82
Senegal	-0.11	Zimbabwe	0.35
Togo	-0.08	*average*	***1.08***
average	***0.52***		
Former Portuguese colonies:		**Former U.S. colony:**	
Angola		Liberia	-0.25
Cape Verde	0.60	**Independent:**	
Guinea-Bissau	-0.26	Ethiopia	0.76
Mozambique	-0.36		
average	***-0.26***	***Ave., all countries***	***0.83***

Table 5. Country average levels of selected efficiency-changing variables

	Former Colonies of:					All
	Belgium	French	Portugal	UK	Other	Countries
No. countries	3	14	4	18	2	41
	(----fraction of country-years----)					
Drought	0.12	0.19	0.25	0.25	0.31	0.22
Conflicts						
Minor	0.10	0.06	0.10	0.06	0.14	0.07
Intermediate	0.05	0.01	0.17	0.03	0.13	0.04
War	0.08	0.05	0.24	0.09	0.28	0.10
Any conflict	0.23	0.12	0.51	0.18	0.55	0.21
Freedom						
Free	0.00	0.05	0.08	0.19	0.00	0.11
Partly free	0.13	0.29	0.21	0.44	0.41	0.34
Any	0.13	0.34	0.29	0.63	0.41	0.45

Table 6. Association between years since independence by 1999 and TFP growth

Years	No. of countries	Shares (%)	TFP by groups (%)
>100	2	7.39	0.71
50-100	1	12.85	1.64
40-49	3	9.82	0.44
30-39	29	62.75	
	Nigeria	16.80	1.59
30-39	28	46.95	0.20
20-29	4	3.68	-0.30
<20	2	2.83	0.38

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Appendix I

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. The Fourier flexible form for a non-periodic function is written as:

$$\text{(A.1)}\quad f_k(x) = u_0 + bx + \frac{1}{2}x'Cx + \sum_{\alpha=1}^{A}\left\{u_{o\alpha} + 2\sum_{j=1}^{J}\left[m_{j\alpha}\cos(jk_\alpha' z) + n_{j\alpha}\sin(jk_\alpha' z)\right]\right\}$$

where x is a *Nx1* vector of variables, b is a *Nx1* vector of coefficients, C is a *NxN* symmetric matrix of coefficients, z is a *Nx1* vector of rescaled values of x, $m_{j\alpha}$ and $n_{j\alpha}$ are coefficients, $k_\alpha' = [k_{x_1}, k_{x_2}, ..., k_{x_N}]$ are multi-indices, *1xN* elementary vectors representing the partial derivatives of the Fourier production function with each set producing a particular Fourier series expansion.

The standard form of a Fourier series is the one defined on the interval $[0, 2\pi]$. Use of a Fourier flexible form requires that the data be scaled so that the difference between the maximum and minimum values of each independent variable does not exceed 2π. The scaling method used here is the one suggested by Gallant (1982).

Let x be variables rescaled by

$$\text{(A.2)}\quad l_i = \ln a_i + \ln x_i > 0 \qquad i=1, 2,\ldots, N$$

where l's are scaled variables and a's are location parameters. Mitchell and Onvural suggested

$$\text{(A.3)}\quad a_i = -Min\{\ln x_i\} + 10^{-5} \quad i=1, 2, \ldots, N$$

The scaled values of the variables are

$$\text{(A.4)}\quad z_{it} = j\lambda k_\alpha' (\ln a_i + \ln x_{it})$$

where the common scaling factor λ is chosen such that z's span the interval $[0,2\pi]$ to reduce approximation problems near endpoints as discussed by Gallant (1981, 1984):

$$\text{(A.5)}\quad \lambda = \frac{(2\pi - \varepsilon)}{\max\{l_i : i = 1, 2, ..., N\}}$$

where ε is an arbitrary small positive value.

Gallant recommended to choose $\lambda = \dfrac{6}{\max\{l_i : i = 1, 2, ..., N\}}$

Consider the vector x to include the five inputs in our application and the variable t representing time as a proxy for technical change.[3] Following Gallant (1982), the multi-indices k_α' are chosen to satisfy the necessary conditions for positive linear homogeneity:

$$\text{(A.6)}\quad m_{j\alpha} = n_{i\alpha} = 0 \quad \text{if } 1'r_\alpha \neq 0 \text{ where } k_\alpha' = (r_\alpha', k_{N+1,\alpha}).$$

That is, we use k_α' to create an index of single time ($\cos(z_t)$ and $\sin(z_t)$), indices of input ratios ($\cos(z_j - z_k)$ and $\sin(z_j - z_k)$), indices of interactions of input ratios and low levels of time ($\cos(z_j - z_k - z_t)$ and $\sin(z_j - z_k - z_t)$) and input ratios and high levels of time ($\cos(z_j - z_k + z_t)$ and

[3] Note that in the text the vector x is partitioned into a vector x of inputs and a scalar t representing technical change. Logarithms were only taken for the inputs, not for t.

$\sin(z_j - z_k + z_t)$). A settings of *A*=45, *J*=1 is used to investigate the production relationship in this paper. Multi-indices that satisfy $\sum_{i=1}^{5} k_{i\alpha} = 0$ and have norm $|k_\alpha| \leq 3$ are constructed (these can be obtained from the authors.) The Fourier flexible form is:

(A.7) $$\ln Y_{it} = u_0 + \sum_{j=1}^{5} b_j x_{ijt} + \frac{1}{2}\sum_{j=1}^{5} c_{jj} x_{jj}^2 + \sum_{j=1}^{5}\sum_{k>j}^{5} c_{jk} x_{ijt} x_{ikt} + b_t t + \frac{1}{2} b_{tt} t^2 + \sum_{j=1}^{5} b_{jt} x_{ijt} t$$

$$+[m_t \cos(z_t) + n_t \sin(z_t)] + \sum_{j=1}^{5}\sum_{k>j}^{5} [m_{jk} \cos(z_{ijt} - z_{ikt}) + n_{jk} \sin(z_{ijt} - z_{ikt})]$$

$$+\sum_{j=1}^{5}\sum_{k>j}^{5} [m_{jk1} \cos(z_{ijt} - z_{ikt} - z_t) + n_{jk1} \sin(z_{ijt} - z_{ikt} - z_t)]$$

$$+\sum_{j=1}^{5}\sum_{k>j}^{5} [m_{jk2} \cos(z_{ijt} - z_{ikt} + z_t) + n_{jk2} \sin(z_{ijt} - z_{ikt} + z_t)]$$

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

Appendix II. Elasticity estimates and percentage of monotonicity violations for different functional forms.

Base Model

Elasticity estimates at sample mean	OLS		Frontier with ECV				
	Cobb-Douglas	translog	translog	**FFF-2**	FFF-20	FFF-40	FFF-60
Land elasticity	0.283	0.288	0.365	**0.314**	0.173	-0.144	0.884
Labor elasticity	0.370	0.362	0.338	**0.426**	-0.178	0.665	-0.432
Livestock elasticity	0.040	0.072	-0.043	**-0.090**	-0.180	-0.451	-0.342
Machinery elasticity	0.110	0.020	0.095	**0.169**	0.073	0.032	0.214
Fertilizer elasticity	0.086	0.162	0.111	**0.089**	0.112	0.105	0.045
Return to scale	0.889	0.903	0.866	**0.908**	0.000	0.206	0.369
Technical change (%)	0.036	0.017	0.475	**0.166**	-0.461	-0.815	-1.242

Violation of positive elasticity (%)	OLS		Frontier with ECV				
	Cobb-Douglas	translog	translog	**FFF-2**	FFF-20	FFF-40	FFF-60
Land elasticity	0.0	28.4	26.8	**27.4**	32.7	6.8	52.4
Labor elasticity	0.0	2.4	0.0	**0.0**	82.4	93.2	14.8
Livestock elasticity	0.0	46.0	47.0	**54.5**	51.7	59.6	73.1
Machinery elasticity	0.0	24.5	5.6	**2.4**	1.8	2.1	9.1
Fertilizer elasticity	0.0	26.5	29.1	**33.4**	36.4	46.5	34.6
Monotonicity	0.0	87.1	84.9	**93.5**	100.0	99.6	99.4

Freedom Model

Elasticity estimates at sample mean	OLS		Frontier with ECV				
	Cobb-Douglas	translog	translog	**FFF-2**	FFF-20	FFF-40	FFF-60
Land elasticity	0.306	0.273	0.168	**0.156**	0.081	0.135	0.048
Labor elasticity	0.339	0.536	0.540	**0.533**	0.218	0.815	0.863
Livestock elasticity	0.026	0.007	-0.007	**-0.008**	0.994	-0.958	-1.656
Machinery elasticity	0.128	0.039	0.178	**0.178**	0.288	0.221	0.320
Fertilizer elasticity	0.090	0.099	0.070	**0.069**	0.014	0.047	0.121
Return to scale	0.889	0.954	0.949	**0.929**	1.595	0.260	-0.304
Technical change (%)	0.569	0.521	0.413	**0.193**	0.149	0.366	0.412

Violation of positive elasticity (%)	OLS		Frontier with ECV				
	Cobb-Douglas	translog	translog	**FFF-2**	FFF-20	FFF-40	FFF-60
Land elasticity	0.0	28.8	30.1	**31.4**	38.3	31.9	39.1
Labor elasticity	0.0	3.6	0.0	**0.0**	23.8	2.4	0.6
Livestock elasticity	0.0	53.7	52.9	**52.4**	0.0	95.9	97.7
Machinery elasticity	0.0	33.7	3.0	**2,4**	10.5	20.4	12.6
Fertilizer elasticity	0.0	26.7	33.6	**34.0**	54.7	45.7	23.1
Monotonicity	0.0	91.6	91.3	**90.8**	89.7	100.0	100.0

Endnotes

[1] The term flexible functional form used in an econometric context would seem to imply that a functional form has some sort of non-parametric properties. It would seem to imply that, even though the flexible form was being treated as if it were the true model in an econometric study, in fact, the inferences are valid against all reasonable true states of nature at least in large samples. The importance of the distinction between Taylor approximation -flexibility and Fourier approximation-flexibility (Gallant calls this Sobolev-flexibility) is that the latter confers non-parametric properties on a functional form. This is the property that a flexible form must possess to eliminate the augmenting hypothesis induced by model specification.

[2] Specifically, a flexible form is Sobolev-flexible if it is possible to choose a sequence of coefficients $\beta_1, \beta_2, \ldots, \beta_K \ldots$, where the length of the vector β_K may depend on K such that

$$\lim_{K\to\infty} K^{m-l-\varepsilon} \left\| f - f_K(\beta_K) \right\|_{l,p,\mu} = 0$$

where f is the true function, g_k is a flexible form, m is the number of times that f is differentiable, l is the largest-order partial derivative regarded as important in the approximation, $\varepsilon > 0$, and for $1 \le p \le \infty$, if any partial derivative of order less than or equal to l is poorly approximated with a probability distribution μ then the distance above will be large. This property of approximating the derivative as well as the function is important for our study.

[3] It is this property that sets it apart form the Translog, the Generalized Leontief, etc. These forms have the ability to achieve a second-order approximation to a twice-differentiable production technology at a given point (Diewert, 1974.) The approximating characteristics of the semi-nonparametric Fourier flexible form holds no matter which of the usual statistical procedures is used to estimate the production technology.

[4] Another important argument is that of White. He demonstrates that OLS estimates of a second-order polynomial such as the 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. Taylor's theorem gives a locally second-order approximation of any function at a certain point but won't warrant a close approximation for the whole sample points. Hence, estimations using a global method, such as OLS, will generally give biased and inconsistent estimates of the derivatives of the Taylor-type function. Conclusions drawn from the models are of limited generality because they merely express empirical results with respect to the performance of these models at the neighborhood of the approximation point.

[5] Gallant likens the problem of choosing the number of terms in the Fourier form, K, to the problem of determining the correct degree of a polynomial fit, or the correct order of a distributed lag, or the correct order when fitting an ARMA process.

[6] On the other hand, Taylor-type flexible forms like the Translog and the generalized Leontief, have been used by researchers to investigate production relationships in dual and primal space (e.g., Chalfant, Christensen et al., Saha et al.)

[7] These counts include the estimation of the parameter γ which is an estimate of the ratio of two standard errors.

[8] Eastwood and Gallant offer rules for choosing the number of Fourier parameters depending on the sample size. Huber shows that the number of parameters required is approximately the sample size raised to the two-thirds power. This principle is especially useful when the objective is the minimization of specification bias for hypotheses testing purposes rather than estimation. Following this rule we should have included 137 Fourier parameters. We instead use the downward selection approach as our interest is estimation of the technical and efficiency change components.

[9] The likelihood-ratio test statistic for both the base and the freedom model for the null hypothesis of no technical change is calculated to be 356.92 and 287.84 respectively, exceeding the 1% critical value 76.15 with 49 degrees of freedom. The likelihood-ratio test statistic for both the base and the freedom model for the null hypothesis of Hicks-neutral technical change is calculated to be 330.2 and 233.68 respectively, exceeding the 1% critical value with 45 degrees of freedom.

[10] The subgroups are: a) irrigation, illiteracy and drought; b) years since independence, English, French and Portuguese dummies; c) small conflict, medium conflict, and war dummies; d) full political and civil liberties, partly political and civil liberties.

[11] Likelihood ratios for the first test are: 441.24 and 303.92 with 15 degrees of freedom for the base and freedom models respectively, rejection at 99% significance level. Likelihood ratios for the second test are: 374.32 and 303.92 with 13 degrees of freedom respectively, rejection at 99% significance level. Likelihood ratios for the third tests also reject the null for all four subgroups at 99% significance level for both models.

[12] The Cobb-Douglas model only includes the linear terms in inputs and time. The Translog model adds the second -order Taylor approximation terms to the Cobb-Douglas form. The first Fourier model includes the Translog model and the first

order Fourier terms of the time trend, $\cos(z_t)$ and $\sin(z_t)$. Ten pairs of first order Fourier terms of input ratios, $\cos(z_{ijt} - z_{ikt})$ and $\sin(z_{ijt} - z_{ikt})$, are added to obtain the next Fourier flexible form. The next model adds the Fourier terms of the form $\cos(z_{ijt} - z_{ikt} - z_t)$ and $\sin(z_{ijt} - z_{ikt} - z_t)$, an addition of 10 pairs. The full model of equation (6) adds the Fourier terms of the form $\cos(z_{ijt} - z_{ikt} + z_t)$ and $\sin(z_{ijt} - z_{ikt} + z_t)$, an addition of 10 pairs.

[13] Most flexible forms such as the Translog or generalized Leotief frequently violate monotonicity and curvature properties.

[14] Likelihood ratio tests for the base and freedom models are 12.2 and 145.8 respectively with 3 degrees of freedom, rejecting the null at the 99% and 90% confidence levels respectively

[15] When Nigeria and South Africa, representing 16 percent and 12 percent respectively of production and have a 1.6 percent TFP growth are purged from the set , weighted average TFP for the rest of the countries is 0.43 percent.

[16] These are Botswana, Gambia, Lesotho, Malawi, Somalia, and Uganda.