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**AGRICULTURAL PRODUCTIVITY IN SUB-SAHARAN AFRICA:  
CARBON DIOXIDE EMISSIONS FROM LAND-USE CHANGE**

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# **AGRICULTURAL PRODUCTIVITY IN SUB-SAHARAN AFRICA: CARBON DIOXIDE EMISSIONS FROM LAND-USE CHANGE**

## **1. Introduction**

The need for increased agricultural productivity through additional cropland has also occasioned increasing rates of deforestation of tropical forests in the world. It is reported that the rapid loss of forest area occurring in Africa represents the highest percentage of any region during the 1980s, 1990s and early 2000s (FAO, 2006). In SSA, agricultural expansion is the main driver of deforestation and direct conversion of forest area into small-scale and large-scale permanent agriculture accounts for approximately 60% and 10% respectively of the total deforestation (FAO, 2002; 2009).

Furthermore, deforestation and forest degradation largely contribute to atmospheric greenhouse-gas emissions. Deforestation causes the carbon stored above and below ground in leaves, branches, stems and roots to be released to the atmosphere. In the tropics, deforestation contributes between 12% and 17% of annual global CO<sub>2</sub> (Houghton 2004; IPCC<sup>1</sup> 2007) although the amount of CO<sub>2</sub> released from forest conversion depends on the conversion rate, the methods, and on the carbon stocks in the vegetation and soil. There is a growing concern to reduce loss in carbon stocks due to deforestation given that large aboveground stock of carbon are put at risk with deforestation.

A way for reducing CO<sub>2</sub> emissions from deforestation will be to slow down the expansion of agricultural land into forests. At the same time, countries in SSA need to increase their agricultural production in order to meet increased food demand and exports in the context of a growing population, and to reduce poverty levels. Indeed, sustainable agriculture implies producing abundant food without depleting the earth's resources or polluting its environment (forests). However, estimates of agricultural productivity in SSA do not account for externalities (negative/or positive) such as CO<sub>2</sub> emissions, soil erosion, and pollution of ground water. This study is an attempt to fill the gap by incorporating CO<sub>2</sub> emissions as an undesirable output in productivity measurements.

## **2. Literature review**

Generally, productivity estimates do not account for externalities (positive or negative) when estimated conventionally. The main reason is that externalities have no price and thus are difficult to value. There is no consensus within the literature on how the adjustment of TFP should take account of externalities. However, there have been a number of developments that attempted to incorporate negative externalities into productivity measurements. They have looked at the derivation of environmentally adjusted productivity estimates.

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<sup>1</sup> IPCC (Intergovernmental Panel on Climate Change)

Perrin and Fulginiti (2001) used a general equilibrium model and derived an algebraic solution for the rate of welfare gain from technological change, in terms of the rate and biases of the change and the size of tax wedges on tradables or nontradables. They showed that the rate of technical change will equal the rate of welfare change in only very unrealistic cases. Using a DEA approach, Zofio and Prieto (2001) calculated efficiency scores that reflect the ability of firms to produce desirable output with the lowest undesirable production. Empirical implications of the DEA process were analyzed considering different regulatory scenarios on CO<sub>2</sub> emissions from the Organization for Economic Cooperation and Development (OECD)'s manufacturing industries. Seiford *et al.* (2002) used the classification invariance property and showed that the standard DEA model can be used to improve the performance via increasing the desirable outputs and decreasing the undesirable outputs.

Färe *et al.* (2004) used an approach which allows explicitly modeling of a joint environmental technology and gauging performance in terms of increased good output and decreased undesirable output. They adopted a directional distance function which was estimated using the linear programming techniques employed in DEA. Rezek and Perrin (2004) used a translog distance function to account for the discharge of pesticide and nitrogen effluents into the environment. They compared traditional and environmental adjusted productivity gains and found that the technical change has been biased toward environmentally friendly production during the last years of the sample period. In another study examining productivity measurements in the presence of market failure, Fulginiti and Perrin (2005) used a general equilibrium model measure of welfare gains from technical change. Their analysis is presented for five different types of "market failures" and found that the rate of technological change, as usually measured from the production perspective, will hardly be an unbiased measure of the welfare benefits of technical change.

Rezek and Campbell (2007) used a distance function framework to estimate the shadow prices of sulfur dioxide (SO<sub>2</sub>), nitrogen oxides, carbon dioxide and mercury emissions. They found that the variation of SO<sub>2</sub> shadow prices is greater than for the other pollutants. Rezek and Rogers (2008) developed a structural production model based on an output distance function and their results suggested that for most of the countries, the CO<sub>2</sub>-saving productivity effect is not large enough to offset the CO<sub>2</sub>-producing scale effect. However, Cuesta and Zofio (2009) departed from an earlier paper (Cuesta and Zofio, 2005) and extended the parametric specification of a translog hyperbolic distance function to mirror the theoretical and non-parametric techniques of Färe *et al.*, who had treated the outputs vector asymmetrically. They applied the method to the U.S. electric utility industry and found that generating capacity and fuel exhibit a relatively large degree of substitutability, while the remaining cross terms are rather low. Wang *et al.* (2012) analyzed input-output efficiency by considering CO<sub>2</sub> emissions. Their results suggest that it is possible to respectively reduce CO<sub>2</sub> emissions by 52% and increase GDP by 63%-75%. Using an output distance function, some studies (Kibonge 2012a, 2012b) examined the effects of CO<sub>2</sub> emissions and total factor productivity rates in SSA.

### 3. Objectives

Estimates of agricultural productivity in SSA do not account for externalities (negative/or positive) such as CO<sub>2</sub> emissions, soil erosion, and pollution of ground water. This study is an attempt to fill the gap by incorporating CO<sub>2</sub> emissions as an undesirable output in productivity measurements. More specifically, the objective of this study is to examine agricultural productivity rates in SSA when the effects of CO<sub>2</sub> emissions from land use change are taken into account.

### 4. Analytical Approach

In order to evaluate the effects of CO<sub>2</sub> emissions from deforestation when estimating TFP growth rates in SSA, two approaches were used that modified traditional TFP measurement. First, traditional TFP growth rates were obtained ignoring CO<sub>2</sub> and deforestation. Then, TFP growth rates were obtained considering CO<sub>2</sub> as jointly produced with agricultural output. 'Corrected' TFP growth rates were estimated accounting for the joint production of CO<sub>2</sub> due to clearing and explicitly considering it a 'bad' output.

In this paper, the basic assumption is that both desirable (aggregate agricultural production) and undesirable outputs (e.g. CO<sub>2</sub> emissions) are simultaneously produced. CO<sub>2</sub> emissions from land use change due to agricultural activities are considered externalities. The multi-output translog distance function is first used to estimate TFP rates in SSA. This approach allows for estimating a multi-output radial TFP growth rate where one output is aggregate production of the sector, and the other is CO<sub>2</sub> emissions due to land clearing. As this approach treats both as 'good' outputs, a production function is also estimated where CO<sub>2</sub> emissions from land clearing are treated as a 'bad' output.

#### - Output Distance Frontier

It is a multiple-input, multiple-output environment where a given set of inputs in the agricultural sector produces two outputs: agricultural commodities, and CO<sub>2</sub> emissions from clearing tropical forests. Following Fulginiti (2010), and Coelli and Perelman (1996), a production technology for the sector is defined.  $P(x)$  represents the set of all outputs vectors, which can be produced, using the input vector  $x \in R_+^M$ , defined as:

$$P(x) = \{y \in R_+^M : x \text{ can produce } y\} \quad (1)$$

The output distance function measures the maximum of proportional expansion in outputs that could be achieved with input quantities held constant. Shephard defines the output distance function in terms of the output set as:

$$D_o(x, y) = \min\{\theta : (y/\theta) \in P(x)\} \quad (2)$$

The output distance function is non-decreasing, positively linearly homogenous and convex in  $y$ , and decreasing in  $x$ .  $\theta$  is the smallest scalar by which all outputs are expanded to reach the frontier.

The relation below means that the distance function will take a value less than or equal to one if the output vector,  $y$  is an element of the feasible production set,  $P(x)$ .

$$D_o(x, y) \leq 1 \text{ if } y \in P(x) \quad (3)$$

$$D_o(x, y) = 1 \text{ if } y \in \text{Isoquant } P(x) = \{y : y \in P(x), wy \notin P(x), w > 1\} \quad (4)$$

The relation above means that the distance function will take a value of unity if  $y$  is located on the outer boundary of the production possibility set.

The output distance function for a given functional form is specified as:

$$\ln D_o = g(x, y) \quad (5)$$

Setting  $D_o = 1$  allows obtaining the frontier surface.

Homogeneity in outputs implies (Shephard):

$$D_o(x, wy) = w D_o(x, y), \quad \text{for any } w > 0 \quad (6)$$

Following Lovell et al. (1994), one of the outputs is arbitrarily chosen such as the  $M$ -th output (in our case the undesirable output), and by setting  $w = \frac{1}{y_M}$  we obtain:

$$D_o(x, y / y_M) = D_o(x, y) / y_M \quad (7)$$

Transforming in logarithms and using a functional form:

$$\ln(D_o / y_M) = g(x, y / y_M) \quad (8)$$

$$-\ln(y_M) = g(x, y / y_M) - \ln(D_o)$$

Technical efficiency is defined as

$$TE = \frac{y_M}{g(x, y / y_M) + v} + \exp(-u) \quad (9)$$

Technical inefficiency effects are defined to be an explicit function of country-specific institutional and political factors that are hypothesized to have influenced the differential performance of countries in SSA.

In the presence of technological change (TC), each observation through time is associated with a different technology. Following Fulginiti (2010), a multi-output distance function to estimate TFP growth is defined, where the technology index  $A_t$  is used as a representation of technical progress that shifts the production frontier across observations. The distance function is modified to include a technology index and is written as

$$D_0^t(x_t, y_t, A_t) = \min\{\theta > 0 : (y_t / \theta) \in P(x_t, A_t)\} \quad (10)$$

For observations on the frontier

$$D_0^t(x_t^*, y_t^*, A_t) = 1 \quad (11)$$

The rate of technical change is defined as

$$\delta_t(x_t, y_t, A_t) = \frac{-\partial \ln D_0^t(x_t, y_t, A_t)}{\partial A_t} = \frac{-\partial D_0^t(x_t, y_t, A_t)}{\partial A_t} \quad (12)$$

Following Fulginiti and Atkinson *et al.* (2003) equation (11) is differentiated and given that the output distance function maintains inputs constant ( $dx=0$ ); it is radial in output space so that  $d \ln y_1 / dA_t = d \ln y_2 / dA_t = \dots = d \ln y_M / dA_t$ ; and equal to the common scalar  $d \ln y_m / dA_t$ ; and that it is linear homogeneous in outputs so that  $\sum_{m=1}^M (\partial \ln D_0^t / \partial \ln y_{mt}) = 1$

Then equation (13) can be derived

$$TC = \delta_t(x_t, y_t, A_t) = \frac{-\partial \ln D_0^t(x_t, y_t, A_t)}{\partial A_t} = \frac{d \ln y_{mt}}{dA_t} \quad (13)$$

Equation (13) indicates that the rate of technical change  $TC$  obtained from an output distance function, equals the common rate of expansion of outputs along a ray through the origin due to an increase in the technology  $A_t$  when inputs are not allowed to change. This paper uses a translog stochastic production frontier where  $TC$  is estimated.

We extend Battese and Coelli (1995) specification to an output distance frontier and write

$$-\ln y^u = g(x, \frac{y}{y^u}, \beta) + v - u \quad (14)$$

where  $y^u$  is the undesirable output (CO<sub>2</sub> emissions from land use change),  $y$  is the aggregate agricultural production,  $x$  is a  $N \times 1$  vector of the logarithm of inputs,  $\beta$  is a vector of unknown parameters, and  $v$  are random variables which are assumed to be iid  $N(0, \sigma_v^2)$ , and independent

of  $u$ .  $u$  is a non-negative random variable distributed iid  $N(\eta, \sigma_u^2)$ , associated with technical inefficiency across production. Note,  $y^u = y_M$  in equation (4.8) above.

Following Battese and Corra (1977),  $\sigma_v^2$  and  $\sigma_u^2$  are replaced by

$$\sigma^2 = \sigma_v^2 + \sigma_u^2 \text{ and } \gamma = \sigma_u^2 / (\sigma_v^2 + \sigma_u^2) \quad (15)$$

$$TC = \frac{\partial g(x, \frac{y}{y^u}, t, \beta)}{\partial t} \quad (16)$$

Equation (16) is described as a shift of the production frontier representing technical change. Technical inefficiency (TE) is captured in equation:

$$TE = \frac{Y}{\exp \left[ g(x, \frac{y}{y^u}; \beta) + v \right]} = \exp(-u) \quad (17)$$

when the frontier approach is used.

Total factor productivity will be calculated as:

$$TFP \text{ (Total factor productivity)} = TC \text{ (technical change)} + EC \text{ (efficiency change)} \quad (18)$$

where EC is the rate at which a country moves toward or away from the production frontier and is obtained by the change in TE between two periods. TE is captured by the non-negative random variable  $u$  and allows for inclusion of potential determinants of country heterogeneity that we referred as “efficiency changing variables”. EC is the rate at which a country moves toward or away from the production frontier. It indicates discrepancies in the productivity performance across countries. The change in TE between two periods is EC.

### - **Production Frontier**

We follow the specification of a stochastic production function proposed by Battese and Coelli (1995) written as

$$\ln y = f(x, y^u, \beta) + v - u \quad (19)$$

where  $y$  is the aggregate agricultural production,  $y^u$  is the undesirable output,  $x$  is a  $N \times 1$  vector of the logarithm of inputs,  $\beta$  is a vector of unknown parameters, and  $v$  are random variables which are assumed to be iid  $N(0, \sigma_v^2)$ , and independent of  $u$ .  $u$  is a non-negative random variable distributed iid  $N(\eta, \sigma_u^2)$ , associated with technical inefficiency across production. Following Battese and Corra (1977),  $\sigma_v^2$  and  $\sigma_u^2$  are replaced by



$$\sigma^2 = \sigma_v^2 + \sigma_u^2 \text{ and } \gamma = \sigma_u^2 / (\sigma_v^2 + \sigma_u^2) \quad (20)$$

$$TC = \frac{\partial f(x, y^u, t, \beta)}{\partial t} \quad (21)$$

Equation (21) is described as a shift of the production frontier representing technical change. Technical inefficiency (TE) is captured in equation:

$$TE = \frac{y}{\exp[f(x, y^u; \beta) + v]} = \exp(-u) \quad (22)$$

when the frontier approach is used.

EC is the rate at which a country moves toward or away from the production frontier. The change in TE between two periods is EC.

Total factor productivity will be calculated as:

$$TFP \text{ (Total factor productivity)} = TC \text{ (technical change)} + EC \text{ (efficiency change)} \quad (23)$$

## 5. Data

The study uses a panel data of 41 countries in Sub-Saharan Africa from 1960 to 2005. Traditional inputs are from the FAO; revised by Fuglie et al. (2008). Efficiency changing variables are also included in the model: years of independence, colonial heritage, war, armed conflicts. The carbon dioxide emissions flux due to land use change by regions in SSA is obtained from Houghton (2004).

### - Output and conventional Inputs data

Output data is from the FAO. It is measured as Agricultural Gross Production (constant 1999-2001, U.S. \$1,000). Input data is from the FAO, but more recent data was supplemented by Fuglie (2008) and used in this paper. Fertilizer is defined as the quantity of fertilizer plant nutrient consumed (tones of N P<sub>2</sub>O<sub>5</sub> plus K<sub>2</sub>O). Agricultural labor is measured as the number of persons (male and female) economically active expressed in thousands. The farm machinery is the number of agricultural tractors in use in agricultural sector (1,000). The livestock variable is the aggregate number of animals "Cattle Equivalents". Agricultural land is the area in permanent crops, annual crops, and permanent pasture; It is a quality-adjusted measure of agricultural land that gives greater weight to irrigated cropland and less weight to permanent pasture (Fuglie).

### - Efficiency-changing variables

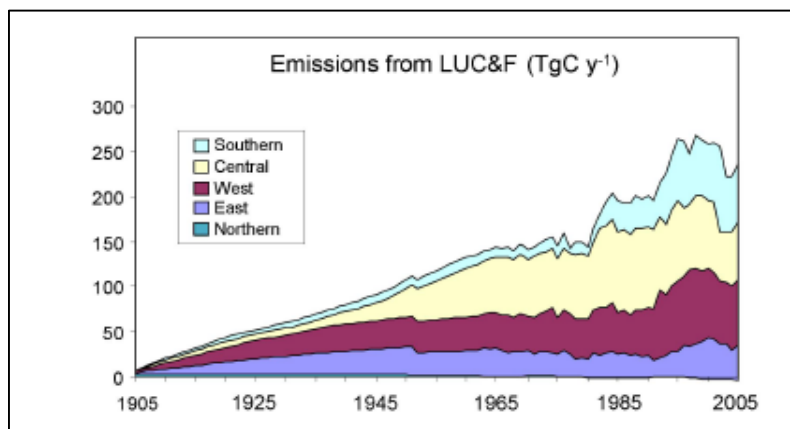
The "efficiency-changing" variables capture heterogeneity in institutional and political environment across countries. "Independence" denotes the number of years that the specific country has been independent and is obtained from the Central Intelligence Agency World Factbook. "Colonial heritage" is represented by four dummy variables for countries that are

former colonies of Great Britain, France, Portugal, and Belgium. “War” is an indicator value describing the intensity of a conflict<sup>2</sup>. “Armed Conflicts” is another indicator value and describes the type of conflict<sup>3</sup>. War and armed conflict variables are obtained from Gleditsch *et al.* (2002), and the Centre for the Study War at PRIO (<http://www.prio.no/CSW/>). It is reported that between 1960 and 2000, 40% of SSA countries had experienced at least one period of civil war, and that in the year 2000 alone, 20% of SSA’s population lived in countries that were formally at war. This problem has been attributed to high levels of poverty, failed institutions, and economic dependence on natural resources (Sambanis and Elbadawi, 2000). In this study, it is expected that civil conflicts and war negatively affect agricultural productivity.

#### - CO<sub>2</sub> emissions from land-use change

Data on CO<sub>2</sub> emissions due to land-use change are obtained from Dr. Richard Houghton (Woods Hole Research Center). Because the focus of this study is on emissions from land-use change due to deforestation, other sources of release of greenhouse gases (methane, nitrous oxide, etc.) due to agricultural activity are beyond the scope and are not considered.

Houghton (2006) reconstructed a history of land use change and a range of plausible estimates of flux, consistent with a number of data sets, from FAO and independent data (figure 1). The method consists of: (i) defining rates of land use change from 1850 to 2000, dividing the types of land used into those that affect the area of forest and those that affect carbon stocks within forests without changing area; (ii) use the bookkeeping model to calculate the annual flux of carbon from these changes in land use and the procedure for initializing the model.



**FIGURE 1: Annual emissions of carbon (TgC y<sup>-1</sup>) from changes in land-use change and forestry in African regions during the period 1900-2005 (source: Houghton, 2003)**

<sup>2</sup> War is coded in two categories: minor (indicator value 1: between 25 and 999 battle-related deaths in a given year), and war (indicator value 2: at least 1,000 battle-related deaths in a given year);

<sup>3</sup> There are four categories of armed conflicts: (i) extra systemic armed conflict that occurs between a state and a non-state group outside its own territory (indicator value 1); (ii) interstate armed conflict that occurs between two or more states (indicator value 2); (iii) internal armed conflict that occurs between the government of a state and one or more internal opposition group without intervention from other states (indicator value 3); and (iv) internationalized armed conflict that occurs between the government of a state and one or more internal opposition group with intervention from other states on one or both sides (indicator value 4).

## 6. Estimation

### - Translog Output Distance Frontier

The translog distance function for the case of 2 outputs ( $y$  and  $y^u$ ) and 5 inputs ( $x_1, x_2, x_3, x_4, x_5$ ) is specified as:

$$\begin{aligned}
 -\ln y_{it}^u &= \alpha_0 + \alpha_1 \ln \left( \frac{y_{it}}{y_{it}^u} \right) + \frac{1}{2} \alpha_{11} \ln \left( \frac{y_{it}}{y_{it}^u} \right)^2 + \gamma_0 t + \gamma_{y1} \ln \left( \frac{y_{it}}{y_{it}^u} \right) t + \frac{1}{2} \gamma_{11} t^2 + \sum_{k=1}^5 \beta_k \ln x_{ik} + \\
 &\frac{1}{2} \sum_{k=1}^5 \sum_{l=1}^5 \beta_{kl} \ln x_{ik} \ln x_{il} + \sum_{k=1}^5 \phi_{1k} \ln x_{ik} \ln \left( \frac{y_{it}}{y_{it}^u} \right) + \sum_{k=1}^5 \gamma_{xk} \ln x_{ik} t + \varepsilon_{it} \quad i = 1, 2, \dots, 41
 \end{aligned} \tag{24}$$

Where  $y_{it}^u$  is the CO<sub>2</sub> emissions from land use change, and  $y_{it}$  is the aggregate agricultural production;  $x_{kit}$  is the  $k$ -th input used by the  $i$ -th country. The model estimated comprises five conventional inputs ( $k$  and  $l$ );  $t$  is the time trend proxy for technical change  $t=1, \dots, 46$ ;  $\alpha, \beta, \gamma, \phi$  and  $\phi$  are the parameters to be estimated. The error term  $\varepsilon_{it}$  has two components:  $v_{it}$  is a random variable which is assumed to be iid  $N(0, \sigma_v^2)$  and independent of  $u_{it}$ .  $u_{it}$  is the one-sided error term distributed iid  $N(\eta, \sigma_u^2)$  used to capture heterogeneity across SSA countries.

The restrictions required for homogeneity of degree +1 in outputs are:

$$\sum_{m=1}^M \alpha_m = 1 \text{ and } \sum_{n=1}^M \alpha_{mn} = 0, \quad m = 1, 2 \quad \text{and} \quad \sum_{m=1}^M \phi_{mk} = 0, \quad k = 1, 2, \dots, 5 \tag{25}$$

The restrictions required for symmetry are:

$$\alpha_{mn} = \alpha_{nm} \quad m, n = 1, 2 \quad \text{and} \quad \beta_{kl} = \beta_{lk} \quad k, l = 1, 2, \dots, 5 \tag{26}$$

The frontier model is specified where the technical inefficiency effects are defined to be an explicit function of country-specific institutional and political factors. The mean of the one-sided error term is expressed as a function of these factors

$$\eta_{it} = h_{it} \delta + \xi_{it} \tag{27}$$

in which  $h_{it}$  is a  $(1 \times p)$  vector of variables that influence the efficiency of the country;  $\delta$  is a  $(p \times 1)$  vector of unknown scalar parameters to be estimated. Random variable  $\xi_{it}$  shares the distributional characteristics of random variable  $u_{it}$ . Negative values of  $\delta$ 's indicate that the particular variable helps in explaining the differential behavior of that observation relative to the ones defining the frontier. The maximum likelihood estimates of the unknown parameters are calculated using the computer program Frontier, version 4.1.

Transformation elasticities and intensity elasticities are calculated following (28) and (29)

$$\lambda_{it} = \frac{\partial \ln \left( \frac{y_{it}}{y_{it}^u} \right)}{\partial \ln y_{it}^u} \quad (28)$$

Where  $y_{it}^u$  is CO<sub>2</sub> emissions and  $y_{it}$  is the aggregate agricultural production.

$$\mu_{it}^1 = \frac{\partial \ln \left( \frac{y_{it}}{y_{it}^u} \right)}{\partial \ln x_{it}} \quad \text{and} \quad \mu_{it}^2 = \frac{\partial \ln y_{it}^u}{\partial \ln x_{it}} \quad (29)$$

The total factor productivity is given by

TFP = Technical Change (TC) + Efficiency Change (EC), where technical change is obtained from equation (16), and EC is obtained from the change in TE between two periods following equation (17).

Note that without imposition of constraints on  $\alpha_1$ , this form treats joint desirable and undesirable outputs symmetrically. We expect then that with the same inputs, this form will indicate a simultaneous increase of agricultural output and jointly produced emissions. As it does not allow distinction between 'good' and 'bad' outputs we expect this form to measure higher TFP than when emissions are omitted.

## - Production Frontier

Imposing symmetry, the translog production function to estimate is:

$$\ln y_{it} = a_0 + \sum_{j=1}^5 b_j x_{ijt} + \frac{1}{2} \sum_{j=1}^5 c_{jj} x_{ij}^2 + \sum_{j=1}^5 \sum_{k>1}^5 c_{jk} x_{ijt} x_{ikt} + b_1 t + \frac{1}{2} b_{tt} t^2 + \sum_{j=1}^5 b_{jt} x_{ijt} t + \varepsilon_{it} \quad (30)$$

$$\frac{1}{2} d_{tt} (y_{it}^u)^2 + d_1 y_{it}^u + \sum_{j=1}^5 d_{jt} x_{ijt} y_{it}^u$$

where  $i=1, \dots, 41$  the countries;  $j$  and  $k=1, \dots, 5$  the inputs:  $x_{ikt}$  (fertilizer, livestock, machinery, labor, land) and  $y_{it}^u$  the CO<sub>2</sub> emissions;  $y_{it}$  is agricultural output;  $t$  is time from 1 to 45 and is used as a proxy for technical change;  $a, b, c, d$  are parameters to be estimated, and  $\varepsilon_{it}$  is the error term. Note that in this approach CO<sub>2</sub> emissions are treated as an additional input in the production of the desirable agricultural output.

The growth rate of aggregate output into contribution from the growth of inputs versus productivity change is obtained from the production function

$$\dot{Y}_{it} = \sum_k \psi_{itk} \dot{x}_{itk} + TFP \dot{P} \quad (31)$$

where  $\psi_{itk}$  is the production elasticity of input  $k$ , for country  $i$ , and year  $t$  calculated as:

$$\psi_{itk} = \frac{\partial f(x_{itk}, y_{it}^u, t, \beta)}{\partial x_{itk}} \quad (32)$$

$$TFP \dot{P} = TC + EC \quad (33)$$

## 7. Results

Table 1 suggests that consistent with theory, the highest TFP growth rates are obtained when using a multioutput distance function that does not distinguish between desirable and undesirable jointly produced outputs (1.39%), followed by the first approach in which emissions are omitted and then by the third when they are included as an additional input in the production of desirable output (0.66% and 0.31% respectively). The evolution of TFP over time shows a similar pattern across the methods: lower TFP growth rates in the 1960s and 1990s, and highest in the 1990s and 2000s.

The results presented in table 1 and figure 2 show that imputing CO<sub>2</sub> emissions to agricultural production lead to lower unexplained TFP rates. By considering CO<sub>2</sub> from land clearing as an input to agricultural production, we obtain 'corrected' TFP growth estimates that punish the sector for the production of a 'bad' (Approach 3). Approach 2 illustrates estimates of TFP when both outputs are explicitly accounted for, with no judgment as to their desirability.

These estimates are consistent with theory and intuition, showing higher growth rates when two outputs are produced rather than one output (Approach 1) with the same inputs. Estimates from this approach are not useful unless additional restrictions are incorporated in estimation that distinguish desirable from undesirable jointly produced outputs, so we restrain from any further analysis

**TABLE 1. Weighted Average SSA's TFP Growth Rates by Decades (%)**

Decades	Approach 1 (No CO <sub>2</sub> )	Approach 2 (CO <sub>2</sub> as Output)	Approach 3 (CO <sub>2</sub> as input)
1960s	0.41	0.64	-0.56
1970s	0.46	1.66	-0.14
1980s	0.54	1.40	0.20
1990s	1.19	1.04	1.27
2000s	1.33	2.62	0.97
1961-2005	0.66	1.39	0.31

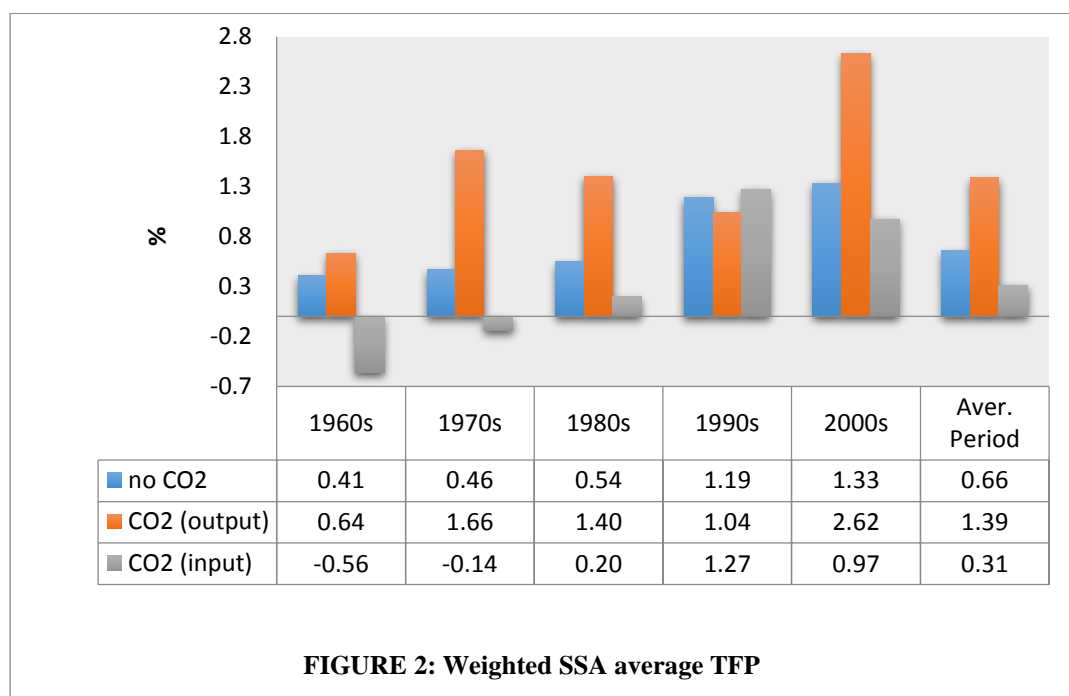


Figure 2 reports the average TFP growth rates by decades. Comparing the two approaches (no CO<sub>2</sub> emissions considered, and CO<sub>2</sub> emissions treated as an input) lead to the following results: on average (ii) TFP growth rates were the lowest in the third approach (0.31%) as treating CO<sub>2</sub> emissions as an input reflects the undesirable character of the negative externality qualifying the measure of TFP growth for all effects, good and bad. Thus, taking CO<sub>2</sub> emissions into account results in lower measured TFP growth rates for all the countries and all decades except in the 1990s (1.27% with CO<sub>2</sub> as an input and 1.19% without CO<sub>2</sub>). A possible explanation is that Central Africa (which accounts for about 40% of CO<sub>2</sub> net flux emissions in Sub-Saharan Africa in the 1990s)

experienced a drop in CO<sub>2</sub> emissions of about -0.03% in the 1990s (CO<sub>2</sub> emissions dropped from 90.0 TgC y<sup>-1</sup> in 1989 to 72.1 TgC y<sup>-1</sup> in 1997. Even though the magnitude differs, the trend across years seems to be similar across all three estimates of TFP growth rates; lowest TFP rates were observed in the 1960s and 1970s, a slow recovery in the 1980s and a marked increase in the 1990s and 2000s.

## 8. CONCLUSIONS

Two approaches that modify traditional TFP measurements were used with the objective of evaluating the effects of CO<sub>2</sub> emissions from deforestation when estimating TFP growth rates in SSA. First, traditional TFP growth rates were obtained ignoring CO<sub>2</sub> and deforestation. Then, TFP growth rates were obtained considering CO<sub>2</sub> as jointly produced with agricultural output. 'Corrected' TFP growth rates were estimated accounting for the joint production of CO<sub>2</sub> due to clearing and explicitly considering it a 'bad' output, then treating it as an additional input in the production of 'good' output. The results suggest that (i) when CO<sub>2</sub> is a joint output of the sector, TFP growth rates are higher as the same amount of inputs are used to produce two outputs instead of one. This is consistent with our expectations because what is being compared is the growth in two outputs (as the output distance function does not differentiate between a desirable and undesirable output) versus the growth of one desirable output, given the same inputs; (ii) When CO<sub>2</sub> emissions due to land clearing are treated as an input to production, it is effectively treated as a 'bad' output, and punishes the sector with lower TFP growth rates.

The results discussed in this section have potential for improvements. First, regarding the construction of CO<sub>2</sub> emissions data, it would be of interest to examine how sensitive TFP estimates are sensitive to different data. In addition, other approaches such as the directional distance function could be used in order to draw more credible and relevant conclusions regarding environmentally adjusted TFP measures. An extension of this study would be to examine the extent to which countries are becoming more efficient over time by increasing desirable output while reducing the CO<sub>2</sub> emissions, using/comparing alternative data on CO<sub>2</sub> emissions from deforestation.

## APPENDIX

### 1. Summary Statistics (1960-2005)

Variables	Units	Min	Max	Mean	Std error
Agricultural Production	Constant 1999-2001 US \$ 1,000	18143	23665208	1412310	2329283
Fertilizer	Tons	10	1235000	38033	121336
Livestock	No. of cattle Equivalents	8297	58628005	5985726	9171429
Machinery	No. of tractors (1,000)	2	175557	6275	21867
Labor	No. of persons (1,000)	75	29162	3378	4146
Land	1,000 hectares	90	45302	3627	5389
Carbon emissions (CO <sub>2</sub> )	TgC y-1	7	94	48	23
Years after independence	Number of years	0	100	28	22
Conflicts	Minor = 1, War = 2	Minor = 14%  War = 2%		Other = 84%	
War	Variables <sup>4</sup>  ES=1,IS=2,IA=3, and IC=4	ES=1.8 %, IS=0.3 %, IA=13.6 %, IC=3 %  Other = 79%			
Former UK colony	Dummy	42% former UK		58% others	
Former French colony	Dummy	34% former Fr.		66% others	
Former Belgium colony	Dummy	7% former Belg.		93% others	
Former Portuguese colony	Dummy	7% former Port.		93% others	

<sup>4</sup> ES=extra systemic conflict, IS=Interstate conflict, IA=internal armed conflict, IC=internationalized conflict



## 2. Coefficient estimates of the translog output distance function

Variables	Coefficients	std error	t-stat
beta 0	-3.844	0.348	-11.046
$\ln(y_1/y_2)$	0.695	0.145	4.805
$\ln(y_1/y_2)$ au carre	0.110	0.019	5.670
$\ln(y_1/y_2) \ln(x_1)$	0.026	0.007	3.733
$\ln(y_1/y_2) \ln(x_2)$	-0.101	0.016	-6.445
$\ln(y_1/y_2) \ln(x_3)$	0.008	0.011	0.671
$\ln(y_1/y_2) \ln(x_4)$	0.017	0.027	0.655
$\ln(y_1/y_2) \ln(x_5)$	-0.140	0.039	-3.541
$\ln(y_1/y_2) T$	-0.005	0.001	-3.296
x1	-0.019	0.037	-0.518
x2	-0.164	0.104	-1.571
x3	-0.094	0.057	-1.671
x4	0.483	0.173	2.783
x5	-0.944	0.192	-4.916
T	-0.001	0.006	-0.154
x1s	-0.016	0.002	-7.457
x2s	0.016	0.008	1.981
x3s	-0.005	0.002	-2.019
x4s	0.105	0.020	5.238
x5s	0.079	0.027	2.947
ts	0.000	0.000	-3.591

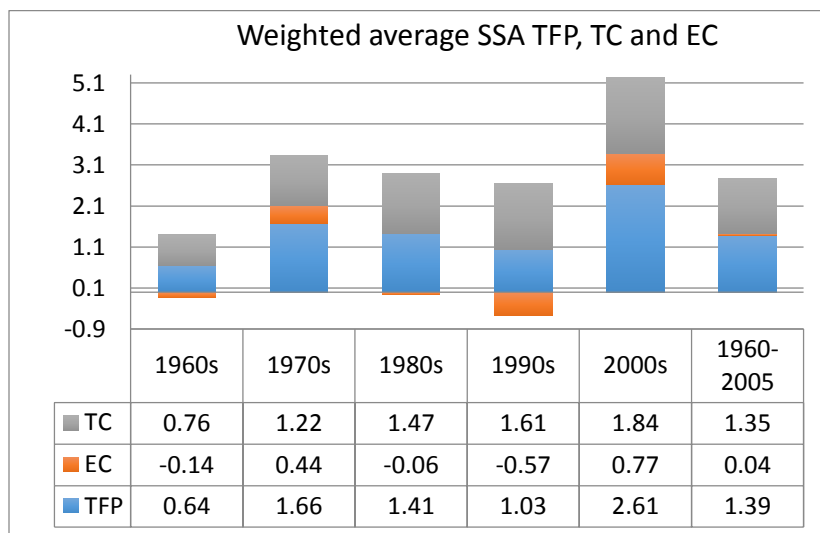
tx1	0.000	0.000	-0.439
tx2	-0.001	0.001	-2.264
tx3	-0.001	0.000	-2.229
tx4	0.005	0.001	4.533
tx5	0.004	0.002	2.182
x1x2	-0.005	0.005	-0.908
x1x3	0.016	0.003	5.171
x1x4	0.036	0.008	4.625
x1x5	-0.038	0.012	-3.163
x2x3	0.036	0.006	6.165
x2x4	-0.112	0.020	-5.687
x2x5	0.180	0.020	8.945
x3x4	0.012	0.012	0.959
x3x5	-0.086	0.015	-5.637
x4x5	-0.153	0.038	-4.076
delta 0	0.620	0.062	10.056
z1 (indep)	0.001	0.000	1.680
z2 (Conflict)	-0.041	0.024	-1.708
z3 (War)	0.006	0.011	0.485
z4 (f. Brithish)	0.048	0.035	1.380
z5 (f.French col)	0.111	0.031	3.564
z6 (f.Portuguese)	-0.306	0.037	-8.275
z7 (f.Belgian Col)	0.558	0.054	10.305

sigma-squared	0.035	0.001	30.181
gamma	1.000	0.001	1626.363

### 3. Intensity Elasticities

Fertilizer	Livestock	Machinery	Labor	Land
<b>0.072</b>	0.221	0.004	0.056	0.468

### 4. Weighted average TFP, TC and EC growth rates (%)



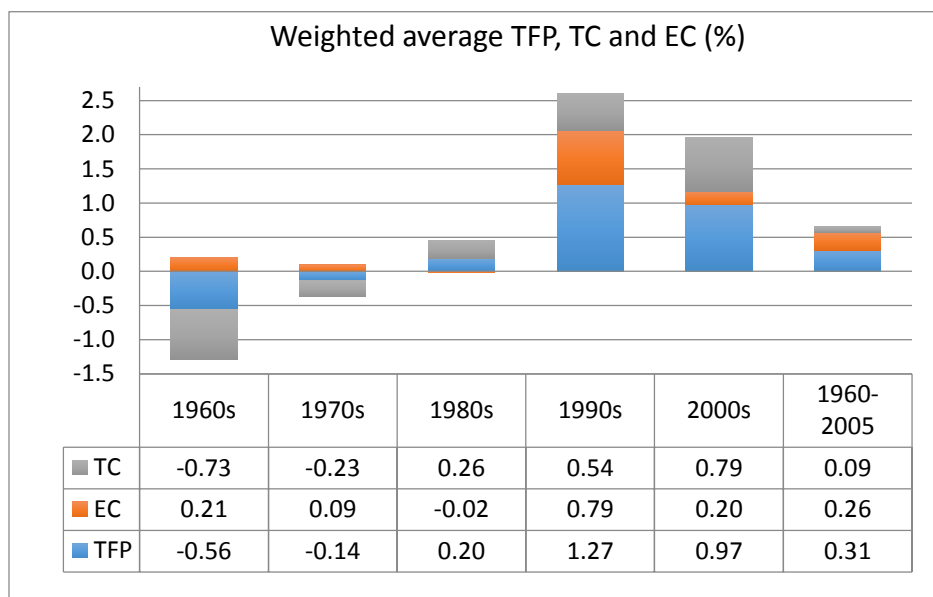
### 5. Coefficient estimates of translog production function

Variables	Coefficients	Std error	T-stat
beta 0	2.136	-1.094	1.952
ln (Co2)	1.523	0.285	5.341
ln (co2) au carre	-0.017	0.029	-0.578
ln (co2) ln (x1)	0.081	0.010	8.095
ln (co2)ln (x2)	-0.105	0.019	-5.466
ln (co2) ln (x3)	-0.122	0.017	-7.281
ln (co2) ln (x4)	-0.246	0.033	-7.554
ln (co2) ln (x5)	0.297	0.043	6.928
ln(co2) T	0.000	0.002	-0.154
ln fertil (ln x1)	-0.264	0.067	-3.928
ln Livestock (ln x2)	1.289	0.154	8.360
ln Machin (ln x3)	0.779	0.100	7.797
ln labor (ln x4)	-0.536	0.225	-2.378
ln land (ln x5)	0.209	0.285	0.734
T	-0.025	0.012	-2.068
x1s	0.025	0.003	9.727
x2s	-0.037	0.008	-4.664
x3s	-0.022	0.003	-6.914
x4s	-0.155	0.019	-8.139
x5s	-0.198	0.026	-7.524
ts	0.000	0.000	2.835

tx1	-0.001	0.000	-2.882
tx2	0.001	0.001	1.977
tx3	0.003	0.001	5.520
tx4	0.007	0.001	5.190
tx5	-0.009	0.002	-4.942
x1x2	-0.021	0.006	-3.731
x1x3	-0.006	0.004	-1.706
x1x4	-0.075	0.008	-9.427
x1x5	0.067	0.013	5.086
x2x3	-0.035	0.007	-5.038
x2x4	0.183	0.020	9.020
x2x5	-0.101	0.022	-4.622
x3x4	-0.093	0.012	-7.830
x3x5	0.162	0.014	11.519
x4x5	0.312	0.038	8.114
delta 0	0.996	0.064	15.452
z1 (indep)	-0.004	0.001	-7.377
z2 (Conflict)	-0.033	0.029	-1.129
z3 (War)	0.024	0.013	1.805
z4 (f. Brithish)	-0.444	0.043	-10.408
z5 (f.French col)	-0.297	0.041	-7.261
z6 (f.Portuguese)	-0.004	0.048	-0.080
z7 (f.Belgian Col)	-2.315	1.489	-1.554

sigma-squared	0.059	0.003	23.573
gamma	0.667	0.064	10.462

## 6. Weighted average SSA TFP, EC and TC



## 7. List of Countries with Respective Ecosystem Regions (Houghton, 2006)

North Africa	West Africa	Central Africa	East Africa	Southern Africa
Algeria	Benin	Burundi	Djibouti	Angola
Egypt	Burkina Faso	Cameroon	Eritrea	Botswana
Libya	Chad	Central African Republic	Ethiopia	Lesotho
Morocco	Côte d'Ivoire	Congo	Kenya	Madagascar
Tunisia	Gambia	Democratic Republic of the Congo	Somalia	Malawi
Western Sahara	Ghana	Gabon	Sudan	Mozambique
	Guinea-Bissau	Equatorial Guinea	Uganda	Namibia
	Guinea	Rwanda	Tanzania	South Africa
	Liberia			Swaziland
	Mali			Zambia
	Mauritania			Zimbabwe
	Niger			
	Nigeria			
	Senegal			
	Sierra Leone			
	Togo			

<sup>a</sup>North Africa was not considered in this analysis.

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