AGRICULTURAL PRODUCTIVITY AND CLIMATE CHANGE IN SUB-SAHARAN AFRICA: WATER SCARCITY, PRECIPITATION AND TEMPERATURE

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Selected Paper prepared for presentation at the Agricultural & Applied Economics Association's
2014 AAEA Annual Meeting, Minneapolis, MN, July 27-29, 2014.

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1. Introduction

There is a growing concern about the effects of climate change on agriculture in the world, especially in Sub-Saharan Africa (SSA). SSA may be among the lowest emitters of carbon dioxide in the atmosphere, but it stands to be the most affected by climate change, which is an additional burden to the already existing challenges faced in the region. Evidence is already emerging that climate change is increasing rainfall variability and the frequency of extreme events such as drought, floods, high temperature, hurricanes, water supply variability and land degradation.

The vulnerability of SSA's agriculture to climate variability is mainly due to its high dependency on rainfall (95% of the agriculture is rainfed) and its limited adaptation capacity to climate change (e.g. low irrigation levels, limited investments in R&D, development of new drought-tolerant and heat-resistant seeds, etc.). As rainfed agriculture dominates agricultural production in these countries, crop yields are exposed and negatively affected by high seasonal rainfall variability.

2. Literature review

Past studies have used a variety of approaches such as crop simulation models (Rosenzweig and Parry 1994; Reilly *et al*. 1996), Ricardian models (Kurukulasuriya *et al*. 2006, Seo and Mendelsohn, 2008), and statistical models (Lobell *et al.* 2008, Schenkler *et al*. 2010). However, few studies have looked at the effect of climate change on agriculture in SSA as a whole. Preliminary results on the potential effects of climate change and water scarcity on agricultural productivity in SSA suggest that temperature and precipitation do contribute in explaining the gap in total productivity performance across countries (Kibonge 2012a, 2012b, 2012c, 2012d, 2011a, 2011b). In addition, there is a need to formally incorporate the effects of water availability in productivity measurements.

3. Objectives

The objectives of this paper are threefold:

(i) To evaluate measures of agricultural productivity in SSA with and without explicit consideration of climate and water related variables as inputs to the production process;

(ii) To explore the potential role of climate change through precipitation, temperature, and irrigation in explaining differences in countries performances;

(iii) To explicitly incorporate the concept of water scarcity in productivity measurements and performance using an indicator of drought developed from the standard precipitation index (SPI). The study uses a panel data set of 41 countries in SSA from 1960 to 2000.

4. Analytical Approach

Stochastic Production Frontier

Following Battese and Coelli (1995), the stochastic production frontier is written as:

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

where Y_{it} is output of the *i*-th country in time period t, x_{it} is a $Nx1$ vector of the logarithm of inputs for the *i*-th country in time period t, β is a vector of unknown parameters, and v_{it} are random variables which are assumed to be iid $N(0, \sigma_V^2)$, and independent of u_{it}. u_{it} is a non-negative random variable distributed iid $N(\eta, \sigma_U^2)$, associated with technical inefficiency across production units.

The parameterization of Battese and Corra (1977) consists of replacing σ_V^2 and σ_U^2 with $\sigma^2 = \sigma_V^2 + \sigma_U^2$ and $\gamma = \sigma_U^2 / (\sigma_V^2 + \sigma_U^2)$. (2)

Following Kumbhakar and Lovell (2000), the growth rate for aggregate production is broken down into contribution from the growth of inputs versus productivity change using the production function (1):

$$\dot{Y}_{it} = \sum_n \varepsilon_{itn} \dot{x}_{itn} + TF\dot{P} \tag{3}$$

where the dot over a variable indicates its rate of change, TFP is the total factor productivity, and ε_{itn} is the production elasticity of input n, for country *i*, and year t calculated as:

$$\varepsilon_{itn} = \frac{\partial f(x_{itn}, t, \beta)}{\partial x_{itn}} \tag{4}$$

TFP growth can be further decomposed into technical change, efficiency change, scale components, and the allocative efficiency change, if information on input prices is available. For simplicity, the *it* subscripts are dropped and the TFP growth can be decomposed as:

$$\dot{TFP} = \dot{TC} + \dot{EC} \tag{5}$$

where TC is the technical change and EC is the efficiency change

$$\dot{TC} = \frac{\partial f(x, t, \beta)}{\partial t} \tag{6}$$

Technical change in (6) is described as a shift of the production frontier representing technical change.

Technical inefficiency (TE) is captured in equation (3-7) below:

$$TE = \frac{Y_{it}}{\exp\left[f(x_{it};\beta)+v\right]} = \exp(-u_{it}) \quad (7)$$

when the frontier approach is used. TE is captured by the non-negative random variable u_{it} and allows for inclusion of potential determinants of country heterogeneity referred as "efficiency changing variables". The frontier model is specified where the technical inefficiency effects are an explicit function of country-specific institutional and political variables that are hypothesized to have influenced the differential performance of countries. The technical inefficiency effect u_{it} is specified as

$$\eta_{it} = h_{it}\delta + \zeta_{it} \quad (8)$$

in which h_{it} is a $(1xp)$ vector of variables that influence the efficiency of the country, and δ is $(px1)$ vector of unknown parameters to be estimated. Random variable ζ_{it} shares the distributional characteristics of random variable u_{it}. The positive values of δ's imply increased technical inefficiency level, while negative values of these parameters indicate improved efficiency. Efficiency change ($\dot{EC}$) 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 $\dot{EC}$.

5. Data

The data used include output (agricultural production), conventional inputs (fertilizer, livestock, machinery, labor and land), and other variables. The other variables include: climatic variables (temperature, precipitation), water scarcity variables (drought, irrigation), and institutions and political variables (the effects of civil war and conflicts, institutional factors such as years after independence, and colonial history). Due to data availability on climate variables, estimation was conducted on a limited number of observations (up to 2000).

- Output and conventional Inputs data

This paper uses data on 41 countries in Sub-Saharan Africa, from 1960 to 2000. Output data is from the FAO[1]. 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_20_5 plus K_20). Agricultural labor is measured as the number of persons (male and

[1] FAO data on output was smoothed by Fuglie (2008) using Hodrick-Prescott filter setting λ=6.25 for annual data.

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

    - Institutions and Political 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[2]. "Armed Conflicts" is another indicator value and describes the type of conflict[3]. 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.

    - Precipitation, Temperature, Irrigation, and Drought.

The data set on precipitation is from the Africa Rainfall and Temperature Evaluation System (ARTES) of the World Bank. This dataset, created by the National Oceanic and Atmospheric Association's Climate Prediction Center is based on ground station measurements of precipitation.

Average Temperature data is from the Tyndall Centre for Climate Change Research (http://www.tyndall.ac.uk/).

Irrigation is the ratio calculated from taking the area equipped for irrigation over the sum of all croplands (from FAO).

[2] 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);

[3] 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).

Drought is a dummy variable obtained from the standard precipitation index (SPI). The SPI for SSA was first constructed (as described in the following section) and later converted into a drought dummy variable by counting all the driest months (SPI lower than -2) in a given year.

- Construction of the Standard Precipitation Index (SPI)

Other research has used a dummy variable to capture drought years. In this study we obtain precipitation data for the years of study by country and proceed to construct the SPI for the region under study. This index, proposed by McKee *et al.* (1993, 1995) for the purpose of defining and monitoring drought, is the most common indicator of drought used by meteorologists. Among the alternative indexes, like the Palmer index, this index is chosen on advice from the National Drought Mitigation Center (NDMC) that constructs and uses this indicator to monitor droughts in the U.S. The SPI is a statistical indicator evaluating the excess or deficit of precipitation over different time scales. It has the advantage to quantify the precipitation deficit for multiple time scales, which represents the effect of drought on the availability of the different water resources (groundwater, reservoir storage, soil moisture, snowpack, and stream flow), while the majority of drought indices have a fixed time-scale. We calculate the index by fitting a gamma distribution to observed values of monthly precipitation at different time steps (e.g. 1, 3, 6, 9 and 12 months), and then transforming back to the normal distribution with mean zero and a variance of one. The SPI is equal to the Z-score applied to normally distributed precipitation totals at different time scales. Durations of weeks or months can be used to apply this index to agricultural interests. This justifies our choice of a 1 month-SPI, more relevant for agriculture purposes, while longer durations of years can be used for water supply.

TABLE 1. Standard precipitation Index values

SPI Values	
2.0+	extremely wet
1.5 to 1.99	very wet
1.0 to 1.49	moderately wet
-.99 to .99	near normal
-1.0 to -1.49	moderately dry
-1.5 to -1.99	severely dry
-2 and less	extremely dry

A drought event occurs any time the SPI is continuously negative and reached an intensity of -1.0 or less (McKee *et al*., 1993). In this study, SPI values were computed for SSA countries from 1960 to 2001 based on precipitation data. Precipitation data were obtained from an average of weather stations for each country and expressed in millimeters (mm). Then a new variable (drought) was created for each country indicating the count of months in a given year with extreme dry droughts reflected by SPI values of -2 and less. SPI indexes were computed for several time scales (1 month, 3 months, 6 months, and 12 months). However, only the 1-month SPI was used to construct the yearly count variables as it provides an indication of crop stress and soil moisture in agriculture. Details on SPI in SSA countries are presented in the Appendix and the software used is from the National Drought Mitigation Center (http://drought.unl.edu/).

It is important to note that the SPI index reflects the drought conditions across time for a particular region and it is not a multilateral index of drought. In this sense, the SPI is important in controlling for drought conditions for a region through time but it fails at capturing cross sectional differences. In an attempt to account for this issue, we do not use the calculated SPI's directly but use it to count the number of drought events in each country through time.

6. Estimation

Agricultural productivity growth rates are estimated in 41 countries in Sub-Saharan Africa, from 1960 to 2000. The production function below is estimated using the stochastic production function approach. Maximum likelihood (ML) procedures are used to estimate the parameters. The stochastic frontier method permits the simultaneous investigation of technical change and technical efficiency change over time.

$$\ln Y_{it} = a_o + \sum_{j=1}^{5} b_j x_{ijt} + \frac{1}{2}\sum_{j=1}^{5} c_{jj} x_{jj}^2 + \sum_{j=1}^{5}\sum_{k>1}^{5} c_{jk} x_{ijt} x_{ikt} + b_t t + \frac{1}{2} b_{tt} t^2 + \sum_{j=1}^{5} b_{jt} x_{ijt} t$$
$$+ d_1 P_{it} + d_2 P_{it}^2 + l_1 h_{it} + l_2 h_{it}^2 + \varepsilon_{it} \qquad (9)$$

where Y_{it} is agricultural output; x_{it} are the logarithms of inputs (fertilizer, livestock, machinery, labor); t is time from 1 to 40 and used as a proxy for technical change; i =1,…,41 countries; j=1,…,5 inputs. P and P^2 are total precipitation and total precipitation squared; h and h^2 are average temperature and average temperature squared; $a, b, c, d_1, d_2, l_1, l_2$ are parameters to be estimated; and ε_{it} is the error term, composed of two random variables:

$$\varepsilon_{it} = -u_{it} + v_{it} \qquad (10)$$

where u_{it} is the one-sided technical inefficiency term assumed at zero and distributed iid $N(\eta, \sigma_U^2)$ that captures heterogeneity across countries. It is hypothesized that inefficiency changes over time and that the inefficiency effects are associated with a number of factors (irrigation, drought, institution, etc.). Following Battese and Coelli, the mean of u_{it} is defined as:

$$\eta_{it} = k_{it}\delta + \xi_{it} \qquad (11)$$

In which k_{it} is a $(1xp)$ vector of variables that influence the efficiency of the country, and δ is a $(px1)$ vector of unknown scalar parameters to be estimated. Random variable ξ_{it} shares the distributional characteristics of random variable u_{it}. The positive values of δ's imply increased technical inefficiency level (i.e. the observation is less efficient) while negative values of these parameters indicate improved efficiency. Random variable v_{it} allows for measurement error and other random factors and is distributed $N(0, \sigma_V^2)$ and independent of u_{it}.

Technical change is calculated as:

$$TC = b_t + b_{tt}t + \sum_{j=1}^{5} b_{jt} x_{ijt} t \quad (12)$$

The simultaneous ML procedure of Coelli's Frontier 4.1 was used to estimate simultaneously equation (9) and equation (10).

In an attempt to explain the differential country performance, nine inefficiency variables were used: drought, irrigation, years after independence, war, armed conflicts, and former colonial heritage (British, French, Belgian, and Portuguese).

7. Results

- Agricultural Performance in SSA

    - Average TFP growth rates

Incorporating climate variables result in lower total factor productivity growth rates as shown in table 2.

TABLE 2. Average weighted[4] SSA TFP growth rate per decade (%)

Decades	TFP	TFP (with climate variables)
1960s	0.41	0.44
1970s	0.46	0.46
1980s	0.54	0.72
1990s	1.19	0.51
1980-2000	0.88	0.61
1960-2000	0.67	0.54

The comparison between TFP growth rates without and with climate variables (table 2) indicate: an increase of 7% in the 1960s, and 31% in the 1980s; a decrease of 57% in the 1990s, a decrease of 30% from 1980 to 2000, and a decrease of 20% throughout the period 1960 to 2000.

[4]TFP, TC and EC for all SSA countries are weighted by output production

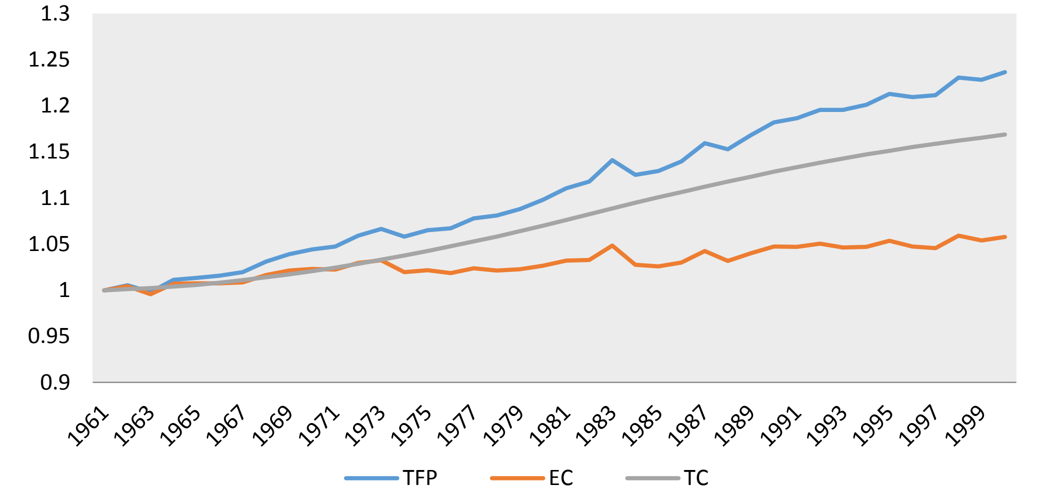


FIGURE 2: SSA TFP, EC and TC growth rate
(Index 1961=1)

Technical change has been increasing through time with a slight decrease observed in the 1990s. Technical change and efficiency change appeared to have played a role in determining the rates of productivity growth.

- Production elasticities

TABLE 3. Production elasticities

Precipitation	Temperature	Fertilizers	Livestock	Machinery	Labor	Land
0.000073	0.000115	0.03	0.11	0.02	0.11	0.60

Linear terms on Precipitation and Temperature were positive and statistically significant, suggesting a positive relationship with agricultural production. The coefficients on their quadratic terms were negative and statistically significant indicating that the effects of temperature and precipitation on agricultural production increase at a decreasing rate. This is consistent with earlier studies (Schlenker and Roberts) pointing out that crops yields positively respond to higher temperature up to a certain level. Their elasticities are low and positive. . Percentage of monotonicity violation is of 34%, 11%, 38%, 37% and 3% respectively for fertilizers, livestock, machinery, labor and land.

- <u>Precipitation and Temperature</u>

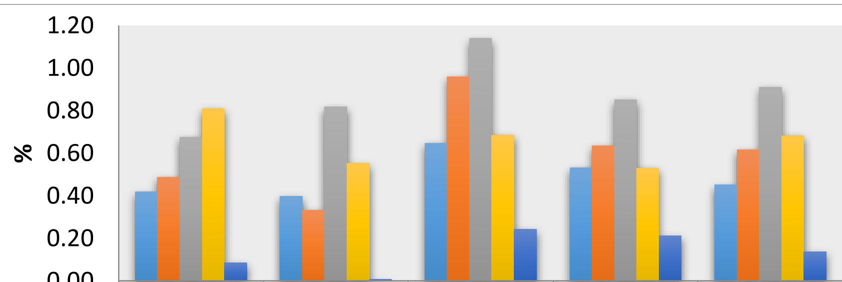
Linear terms on Precipitation and Temperature were positive and statistically significant, suggesting a positive relationship with agricultural production. The coefficients on their quadratic terms were negative and statistically significant indicating that the effects of temperature and precipitation on agricultural production increase at a decreasing rate. This is consistent with earlier studies (Schlenker and Roberts) pointing out that crops yields positively respond to higher temperature up to a certain level. Their elasticities are low and positive. Other input elasticities are all positively associated with aggregate production. Livestock, labor and land do have a greater effect on the output.

- <u>Drought and Irrigation</u>

The coefficient on drought was statistically significant and suggests that taking it into account decreases inefficiency across countries in SSA. Overall, some of the countries with the lowest precipitation amount and with the most frequent extreme drought episodes have also experienced lower TFP growth rates, except Sudan as shown in Appendix. The coefficient on Irrigation was statistically significant and does contribute in explaining the discrepancy across countries.

Other factors that account for heterogeneity across countries were all also significant; years after independence and colonial heritage (United Kingdom, France and Portugal) were statistically significant and indicate an improvement in inefficiency when accounted for. The war variable was statistically significant and implies an increase in inefficiency across countries.

- <u>Regional Evolution</u>



	1960s	1970s	1980s	1990s	Average
Central Africa	0.42	0.40	0.65	0.53	0.45
Southern Africa	0.49	0.33	0.96	0.64	0.62
East Africa	0.68	0.82	1.14	0.85	0.91
West Africa	0.81	0.55	0.69	0.53	0.68
Sahel	0.09	0.01	0.24	0.21	0.14

FIGURE 3: Average SSA TFP with climate variables

Figure 3 shows the average weighted TFP growth rates by region when climate variables are included. Overall, East Africa, West Africa and Southern Africa have consistently performed better throughout the period 1961-2000 than the other regions with averages of 0.91%, 0.68%, and 0.62% respectively. The Sahel experienced the lowest performance with an average of 0.14% (lowest level in the 1970s with 0%). This is not surprising as part of the Sahel is a desert and not very suitable for agricultural activities. Besides, some countries in the Sahel have been experiencing more frequent and severe drought episodes as shown in the precipitation and drought data.

TABLE 4. Comparison of average weighted TFP growth rates by region (%) – with and without Climate Variables

REGIONS	1960s	1970s	1980s	1990s	1960-2000	Change (%)
Central A.	0.29	0.37	0.72	0.62	0.51	-0.11
Central A. (WV*)	0.42	0.40	0.65	0.53	0.45	
Southern A.	0.68	1.07	0.42	0.95	0.80	-0.23
Southern A. (WV*)	0.49	0.33	0.96	0.64	0.62	
East A.	1.28	0.35	1.07	0.98	0.94	-0.02
East A. (WV*)	0.68	0.82	1.14	0.85	0.91	
West A.	-0.32	0.26	0.58	1.77	0.59	0.17
West A. (WV*)	0.81	0.55	0.69	0.53	0.68	
Sahel	0.30	0.33	-0.09	1.02	0.45	-0.70
Sahel (WV*)	0.09	0.01	0.24	0.21	0.14	

*WV=weather variable

On average, all regions have experienced a lower TFP growth rates when weather variables are taken into account (table 4): Central Africa has experienced a reduction of 11% in TFP growth rates; Southern Africa has experienced a reduction of 23% in TFP growth rates; East Africa has experienced a reduction of 2%; West Africa has experienced an increase of 17%, and the Sahel a reduction of 70%. Agricultural productivity rates in the Sahel and Southern Africa appear to be more sensitive to weather variables. These two regions have also been experiencing more frequent drought events than others, reflected by lower annual precipitation levels. East Africa and Central Africa TFP growth rates have not changed much once the weather-related variables are taken into account (reduction of 0.02% and 0.11% respectively). West Africa experienced an increase of 0.17% once the weather-related variables are accounted for. The results discussed above provide an indication on the contribution of temperature and precipitation in explaining TFP growth rates over time. They have positive effects on the aggregate agricultural production though they grow at a decreasing rate. The results also show that irrigation and drought contribute in explaining the difference in countries TFP's performances. Some countries are more vulnerable to climate variability and water scarcity than others, reflected by the difference in TFP growth rates when compared to our earlier estimates (when weather variables are not included). The results also show that SSA is very heterogeneous region with respect to its agro-ecological zones and therefore respond differently to water resources and climate variability.

8. CONCLUSIONS

In this second section, Precipitation, temperature, drought and irrigation were incorporated in productivity measurements. The results indicate that total factor productivity has experienced a positive evolution in sampled countries and the region exhibited annual productivity gains of (averages of 0.61% between 1980 and 2000; 0.54% between 1960 and 2000). The results also indicate that agricultural productivity in SSA is sensitive to climate variability. Precipitation and temperature have a positive effect on agricultural production up to a certain threshold where floods and very high temperature seems to be important. Once drought is accounted for, the gap in countries performance decreases, while accounting for irrigation increases the performance discrepancy across countries.

Temperature and precipitation vary considerably across different countries and even within countries. After dividing the countries by regions based on Agro-ecological zones, the results obtained suggest that West Africa and East Africa performed the best with respect to their agricultural productivity rates (averages of 0.91% and 0.68 %, respectively), as reflected by relatively higher TFP growth rates throughout the period. The Sahel had the poorest performance with an average of 0.13% from 1960 to 2000. Taking water-related variables into account results in lower estimates of agricultural productivity rates, which indicates that we are indeed, successful at controlling for these episodes and reducing ignorance in productivity measurement for this region. Other factors that accounted for heterogeneity across SSA countries such as years after independence and colonial heritage (United Kingdom, France and Portugal) indicate an improvement in efficiency. War variable implies an increase in inefficiency across countries when included in productivity measurement.

Following our results, institutional variables as well as weather-related variables do contribute in explaining the countries performance with respect to their agricultural productivity growth rates. The vulnerability of agriculture in SSA to climate change and water scarcity constitutes additional constraints to increased agricultural productivity rates and poverty reduction. Indeed, water availability is expected to worsen with climate change, especially in drought-prone regions such as the Sahel. We also provide evidence of the sensitivity of the sector to these variables, indicating increased vulnerability of the region's agricultural production given climate change prospects. This implies that, if the IPCC forecasts for the region are realized, there will be a deterioration of food security in a region that is already food insecure. Investments in mitigation strategies (irrigation projects, etc.) will therefore have even higher returns in Africa than in other regions.

A follow-up on this study is to gather most recent data on weather variables (mainly precipitation, temperature, other indicators of water availability used for agricultural purposes). Some possible extensions of the study would be: (i) to examine mitigation strategies to adopt in SSA countries: dry regions (e.g. Sahel) versus in wet regions (mainly rainfed); (ii) Examine the status of water productivity on some countries in SSA and ways to calculate/estimate it; (iii) Examine the association between water productivity and agricultural productivity – Does agricultural performance improves as water productivity increases.

APPENDIX

1. Summary Statistics

Variable	Units	Mean	Min	Max	Std dev
Output and Inputs					
- Output	Constant 1999-2001 US$1000	1230536	4760	24609802	2255978
- Fertilizer	Metric tons	33468	1	1235000	112586
- Livestock	Number of cattle equivalent	89	16	218	28
- Machinery	Number of tractors (1,000)	5396	1	175557	20167
- Labor	1,000 persons	92	18	343	33
- Land	1,000 hectares	19760	3	130494	25344
- Precipitation	Millimeters	3450	24	40560	989
- Temperature	Degree Celsius	24.2	11.1	29.4	3.4
Other Factors					
- Independence	Years after independence	28	0	100	24
- Irrigation	Ratio of area irrigated / total croplands	0.11	0.001	1.33	0.18
- Drought (Count variable)	Number of months with SPI < -2 in a year	0.2	0	4	0.5
- Conflicts	Minor=1, war=2	Minor =13% War = 8%		Other = 79%	
- War	Variables[5] ES=1,IS=2,IA=3, and IC=4	ES=2.3%, IS=0.4%, IA=14.8%, IC=3.3% Other = 79%			
- Former British colony	Dummy Former col=1, otherwise=0	41% former British		49% others	
- Former French colony	Dummy Former col=1, otherwise=0	34% former Fr.		66% others	
- Former Belgium colony	Dummy Former col=1, otherwise=0	7% former Belg.		93% others	
- Former Portuguese colony	Dummy Former col=1, otherwise=0	7% former Port.		93% others	

[5] ES=extra systemic conflict, IS=Interstate conflict, IA=internal armed conflict, IC=internationalized conflict

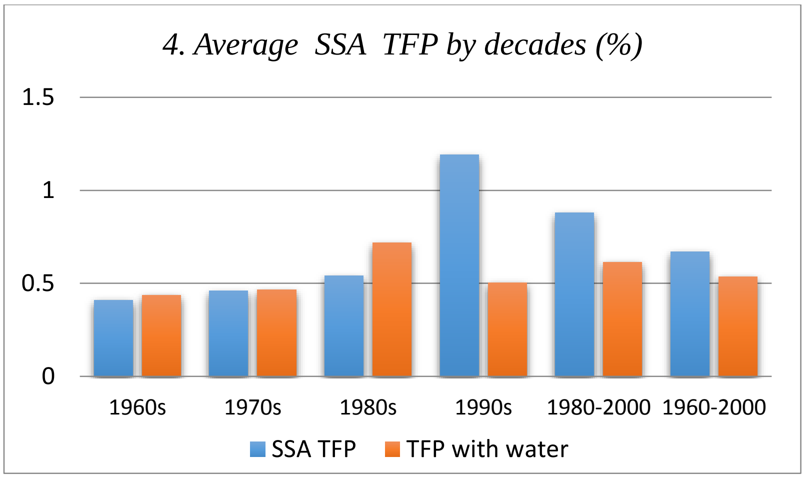
2. Results Stochastic Production Frontier

Variables	Coefficients	Std error	T-ratio
Constant	3.272	0.515	6.353
Fertilizer (X1)	0.095	0.040	2.372
Livestock (X2)	0.269	0.107	2.499
Machinery (X3)	-0.019	0.061	-0.319
Labor (X4)	-0.765	0.199	-3.849
Land (X5)	1.519	0.204	7.433
Time (T)	0.014	0.007	2.081
Precipitation	0.000	0.000	7.894
Precipitation Squared	0.000	0.000	-5.799
Temperature	0.114	0.022	5.192
Temperature Squared	-0.002	0.001	-4.558
X1 squared	0.027	0.003	9.750
X2 squared	0.015	0.008	1.964
X3 squared	-0.011	0.003	-3.710
X4 squared	-0.137	0.022	-6.322
X5 squared	-0.016	0.028	-0.564
Time squared	0.000	0.000	-0.608
*X1 * T*	0.001	0.000	2.896
*X2 * T*	-0.001	0.001	-0.893
*X3 *T*	0.002	0.000	4.128
*X4 * T*	0.005	0.001	4.651
*X5 * T*	-0.008	0.001	-5.800
*X1 * X2*	-0.021	0.006	-3.668
*X1 * X3*	-0.023	0.004	-6.260
*X1 * X4*	-0.068	0.008	-8.157
*X1 * X5*	0.056	0.015	3.845
*X2 *X3*	0.000	0.007	-0.032
*X2 * X4*	0.160	0.020	7.874
*X2 * X5*	-0.216	0.021	-10.209
*X3 * X4*	-0.061	0.012	-4.899
*X3 * X5*	0.105	0.015	6.976
*X4 * X5*	0.195	0.042	4.629
Constant	0.798	0.066	12.054
Years Independence	-0.003	0.001	-5.866
Conflicts	-0.057	0.029	-1.998
War	0.030	0.013	2.255
Great Britain FC	-0.288	0.043	-6.654
French FC	-0.112	0.044	-2.576
Belgium FC	0.140	0.049	2.868

Portuguese FC	-1.932	0.126	-15.372
Drought	-0.033	0.012	-2.734
Irrigation	0.429	0.062	6.890

3. Production elasticities

Precipitation	Temperature	Fertilizers	Livestock	Machinery	Labor	Land
0.000073	0.000115	0.03	0.11	0.02	0.11	0.60



5. List of Countries by Agro-Ecological Zones

Southern Africa	**Sahel**	**Central Africa**	**West Africa**	**East Africa**
Angola	Senegal	Burundi	Benin	Ethiopia
Botswana	Mauritania	Cameroon	Côte d'Ivoire	Kenya
Lesotho	Mali	Central African Republic	Gambia	Somalia
Madagascar	Burkina Faso	Congo	Ghana	Tanzania
Malawi	Niger	Congo, Democratic Republic	Guinea	Uganda
Mozambique	Nigeria	Gabon	Guinea-Bissau	
Namibia	Chad	Equatorial Guinea	Liberia	
South Africa	Sudan	Rwanda	Sierra Leone	
Swaziland			Togo	
Zambia				
Zimbabwe				

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