Agricultural Productivity, Drought, and Economic Growth in Sahel

Inoussa Boubacar
University of Wisconsin - Stout
boubacari@uwstout.edu

Selected Paper prepared for presentation at the Southern Agricultural Economics Association Annual Meeting, Orlando, FL, February 6-9, 2010

ABSTRACT

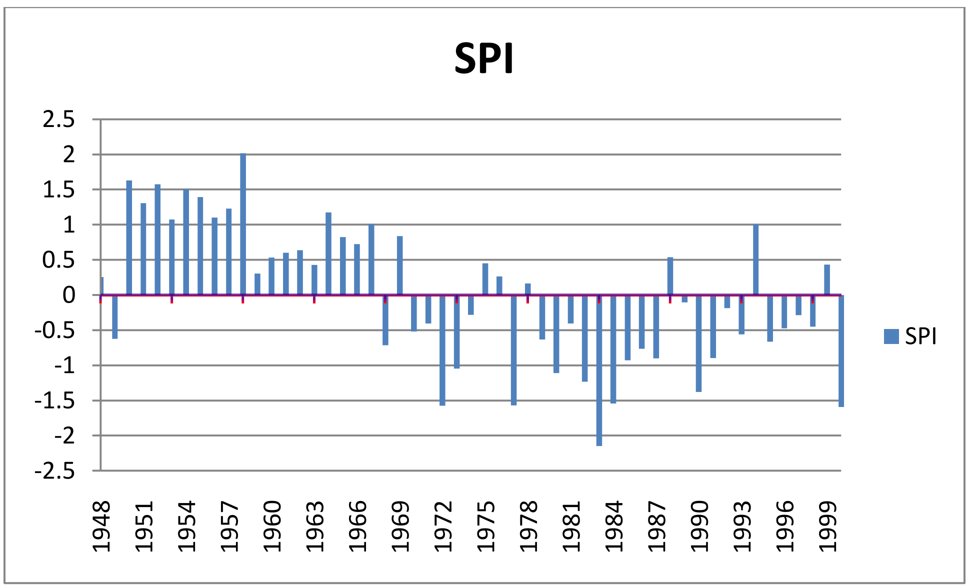
A standardized precipitation index is used in a regression analysis to quantify the impact of climate change on agricultural productivity in Sahel. I first estimate a Malmquist productivity index and its efficiency and technical change components. I further assess the statistical significance of the indices by estimating some confidence intervals via a bootstrap method. In the second stage of the analysis, I use a Probit model to estimate the extent to which climate variables affect agricultural productivity. It appears that agricultural performance has been disastrous in many Sahelian countries from 1970 to 2000. Using a comparable cross-country measure of drought, I provide evidence that precipitation variability is constraining not only Sahel's agricultural performance but also its economic growth. War also plays an equally detrimental role as drought in explaining the causes of Sahel's economic downturn.

JEL Classification: O13, O55, Q54

Keywords: Productivity, Agriculture, Sahel

I: Introduction: Many observers (InterAcademy Council, 2004; FAO) argue that the issue of food insecurity is pressing in most African countries. The prevalence of undernourishment in five of the eight countries in Sahel is higher than the average of developing countries[1]. There is a strong belief that the issue of food insecurity will get even more critical in the future because of the combination of a high population growth and a sluggish agricultural productivity growth. While population growth has sharply declined in Latin America and the Caribbean and also in South-Eastern Asia regions[2], it has rather increased in West Africa.[3] With a limited access to capital, as the population pressure becomes high, the agricultural development will take the path of labor-led intensification[4] (Carswell, 2000 cited by Aune and Bationo, 2008). In Sahel, this type of intensification is common as farmers are reluctant to adopt yield-enhancing technologies because of the prevalence of risks associated with drought and pest attacks (Aune and Bationo, 2008). As evidenced by Figure 1 below, drought has been chronic rather than episodic in Sahel.

Figure 1: Drought in Sahel: Standardized Precipitation Index



Although the causes of the decline in precipitation are still being debated, the changes in rainfall will certainly have a wide range of economic consequences. Africa is seen as the most vulnerable continent to the devastating effects of climate change (IPCC, 1998). Moreover, many observers (IPCC[5], 2007; Mendelsohn, Dinar, and Dalfelt, 2000) argue that the most direct impact of climate variability in African countries is on agriculture because of the importance of the sector in their economies.[6]

Yet, little is known about the magnitude of the impacts of climate variability at the country or regional level in tropical areas (Mendelsohn et *al.,* 2000). Few economic studies have measured the climate sensitivity of African agriculture. Mendelsohn *et al.* (2000) employ a simulation method using an IPCC forecast of future atmospheric carbon dioxide levels of 2100 to study the impacts of climate change on African agriculture. While they find the effects to be different across sub-regions within the African continent, they support that all the regions will experience some negative effects. West Africa suffers the greatest losses, ranging from 36 % to 44 % of the losses for the entire continent. These damages amount between 42 and 60 % of the region's agricultural gross domestic product (GDP).

Maddison, Manley and Kurukulasuriya (2007) use a Ricardian approach to estimate the effects of predicted changes in climate. Their results confirm that the African agriculture is vulnerable to climate change. Their estimates suggest production losses of 19.9 percent for Burkina Faso and 30.5 percent for Niger by year 2050, under the assumption of perfect farmers' adaptation to climate change.

Kurukulasuriya *et al.* (2007) use a cross-sectional Ricardian method based on survey data on 9000 farmers across 11 African countries to estimate the impact of current temperature and precipitation on farm net revenues. They define total farm net revenue as the sum of dryland crops, irrigated crops and livestock activities. They find that dryland crop farmers are the most vulnerable to an increase in temperature. Although the coefficients on precipitation are frequently not statistically significant, the authors conclude that net revenues for dryland crops will increase with more precipitation and decrease when precipitations fall.

One common problem with the above studies is the proxy used for their climate variables. The average annual value of precipitation is a poor measure of climatic change. It has no meaningful explanation in a cross-country study as an average precipitation in one country is surely not comparable to an average precipitation in another country.

The second flaw that can be held against the bulk of previous studies is their methodological approach which is based on the Ricardian model. The accuracy of the Ricardian approach in climate sensitivity rests on the assumption that land value reflects the true value of the agricultural products. This is a very restrictive assumption because of the well documented fact (Deschenes and Greenstone, 2007) of government interventions to distort prices in developing countries. Therefore, the quality of the data on price is questionable. The accuracy of the Ricardian model in its simple form is further impeded by the lack of well defined property rights in Africa (Vyas and Casley, 1988; Aune and Bationo, 2008). Also, some aspects of future climates may differ from the present, and the Ricardian models will fail to properly incorporate the possible effects of adaptations to climate change (Kurukulasuriya *et al.* (2007).

Using survey data, Sakurai (1997) analyzes crop production under drought risk and the demand for virtual drought insurance in Sahel. His panel data covers the period from 1981 to 1984 with a sample of 89 households in Burkina Faso. His model specification is a modified Cobb-Douglas function with interaction terms between traditional inputs and a drought dummy variable which is defined as a year with precipitation lower than the long-term average. This is a faulty definition of drought. Not only does it rely on a dummy variable to capture the effect of drought, but also the term “long-run average” is vague because there is no clear cut off of how long a period must be in order to be considered “long-term”.[7]

The reference to a dummy variable as a measure of drought is also used by such authors as Thiele (2003). Additionally, other authors such as Le Nay and Jean (1989); Roncoli, Ingram and Kirshen (2001); and Little *et al.* (2006) use the subjective assessment of country experts to construct their drought dummy variable.

As it is well expressed in Boubacar (2008), one of the flaws that are often held against previous impact studies is their incapacity to launch the debate on the economic impact of drought because of their faulty drought measure. Even recent studies fail to accurately account for drought. For example, Barrios; Ouattara and Strobl (2008) use a weighted mean of annual values of temperature and precipitation as their climate variables. Lio and Liu (2008), in their analysis of governance and cross-national agricultural productivity difference, skim the role of precipitation. As in many previous studies explaining cross-country agricultural productivity, their measure of climate variable is an average annual precipitation.

Admittedly, in both the Ricardian and the production function approach, the use of annual average values of climate variables such as temperature and precipitation is not appropriate in places where rainfall is received only for 3 to 4 months during a year. To better capture the impact of temperature and precipitation on agricultural production, one needs to use the values of those variables during the growing season. And with respect to precipitation, a comparable measure across regions must also be used in lieu of average value.

Even after putting aside the issue of the drought variable used in previous studies, the battery of theories put forward to account for Africa's agricultural performance present mixed evidence. The theories can be categorized in two groups.

The first wave of research (Vyas and Casley, 1988; Jaeger, 1992; Trueblood and Coggins, 2003) depicts a dismal growth. As recently as 2002, to address the challenge of agriculture and the associated widespread food insecurity in Africa, the Secretary General (SG) of United Nations (UN) has solicited the Inter-Academy Council (IAC) to provide "technological strategic plans for harnessing the best science and technology to produce a substantial increase in agricultural productivity in Africa" IAC (2004). The concern expressed by the SG of UN highlights the region's poor performance in agricultural production. Recently, Aune and Bationo (2008) also share the dismal view of the agricultural development in the drylands of West Africa. They describe the process of agricultural intensification as climbing a ladder, with different distances between different steps. They conclude that the difficulty of the intensification is explained by the constraints related to climate, poor soil quality, a distorted market, poor institutions, and a lack of infrastructure.

On the other hand, the more optimistic view of the recovery of African agriculture is shared by such researchers as Block (1995), Lusigi and Thirtle (1997), Fulginiti *et al.* (2004), Pratt and Yu (2008). The magnitude of the increase in productivity depends on the study. A common mistake with many papers is that they ignore regional disparities within the African continent. For example, Pratt and Yu (2008) credited only four countries for the widely reported African agricultural performance of the 1980s. According to the authors, Nigeria, Ghana, Tanzania and Sudan explain 94 percent of TFP growth from 1984 to 1993 in Sub-Saharan Africa. Thus, the pattern of agricultural productivity in Africa, as conveyed by the more optimistic approach should be vigilantly interpreted. As noted by William Cline (2007), the performance of the agricultural productivity in Africa as a bloc is mostly driven by Nigeria and Egypt because not only do those two countries alone represent the majority of output base in Africa, but also the Egyptian agricultural is entirely irrigated using the Nile water. Therefore, the results may be biased against countries without irrigated agriculture. For example Cline (2007), in his study of country-level agricultural impacts, contrasts his estimates with and without Egypt. He finds a decline of 31 percent in the median change in net revenue due to climate change in dry-land Africa as opposed to an increase of 24.4 percent when Egypt is included in the sample. Of course, critics may argue that he uses a Ricardian approach that includes a linear and quadratic terms in average annual temperature and precipitation.

Undoubtedly, attributing the performance of agricultural productivity to improved weather conditions in Africa (Block, 1995) seems to clash with the reality on the ground, at least in many countries in Western Africa. IPCC (1996) reports that droughts are locally frequent every year and continental crises surface once or even twice every decade in Africa. This view reinforces the findings by Sanders, Shapiro, and Ramaswamy (1996, page 8) who state that "since 1968, there have been several acute droughts (in Sahel) and rainfall was approximately one standard deviation below the long-run normal". With very few exceptions, Figure 1 shows that the period of 1969 and afterward is characterized by recurrent droughts in Sahel. A semi-arid zone, a gateway between the Sahara desert and the humid tropical Africa, covering an area equal to 5.4 million km^2, situated approximately between 12° and 18° North, Sahel has only one yearly rainy season, and very often the bulk of the rainfall is concentrated during the months of July-August. Numerous studies (Dixon et *al*, 1999) indicate that irrigation is rare in Sub-Saharan Africa and Sahel is not an exception. According to IPCC (1996), only 7 percent of total land is irrigated in the Sahel Region. This absence of irrigation renders agricultural production dependent on rainfall and very sensitive to climate variability. The combination of recurrent droughts (see Figure 1) and high mean temperature (see Table 2) creates an unfavorable soil-water balance.[8]

In sum, Sahel faces very high temperatures, chronic droughts, and possesses a very low irrigated land. This is a highly unfavorable agricultural condition, even for developed nations.

The conflicting views expressed by the existing studies on African agricultural productivity in general and the impact of climate in particular has motivated this paper. I intend to bring into consideration factors thus far neglected and whose role should not be overlooked in explaining the causes of the decline of the observed productivity losses. In this paper, I use a newly comprehensive climate data set to construct a comparable drought index across all countries in Sahel with the following three objectives in mind:

First, I will compute the Malmquist index for the agricultural sector, a measure of total factor productivity. The statistical significance of the Malmquist index is assessed using a bootstrap method to construct confidence intervals around its values.

Second, I will use the estimated Malmquist index to analyze the causes of the decline in productivity with particular focus on drought and temperature.

Finally, using annual growth rates of real per capita GDP,[9] and climate variables, I will study the link between economic growth and chronic droughts. Trends in drought index confirm that precipitation has been on a steady decline since the end of 1960s. In a cross-country analysis, Barrios, Bertinelli and Strobl (2003) find that rainfall has a significant impact on growth only in the African sample.

The rest of the paper is organized as follows. Section 2 discusses the methodological framework and the data used in this study; section 3 presents the research findings; section 4 extends the analysis to include the impact of drought on the annual growth rates of real per capita GDP and real per capita agricultural GDP; and section 5 concludes.

II: Methodology

Productivity is a measure of the performance of a production process using several inputs to produce one or several outputs. The measure of productivity that involves the ratios of outputs to inputs is referred to as total factor productivity (TFP). However, the ratio of outputs to a particular input is known as partial factor productivity (PFP) measure. With respect to TFP, the need to aggregate outputs and inputs becomes apparent. Associated to the many ways of measuring total input and total output, are the different methods to estimate TFP. Broadly speaking, two approaches have been used to measure TFP. In effect, one can distinguish between the parametric approach and the nonparametric approach. The two approaches differ in their assumptions with regard to the existence of a random error and efficiency.

For the purpose of this study, the measure of productivity is the non-parametric (output oriented) Malmquist index as explained in Caves *et al* (1982), popularized by Fare *et al* (1992), and used by Fulginiti and Perrin (1997), Pratt and Yu (2008) among others.

In the next three sub-sections, I will briefly discuss the methodology for computing the Malmquist index, describe the variables used, and finally specify the empirical models.

2.1: The Malmquist Productivity Index

I will define and decompose the nonparametric Malmquist productivity index, in accordance with Fulginiti and Perrin (1997). The interested reader can refer to their article for a discussion of ideas in support of Malmquist index in productivity studies.

The Malmquist index is a nonparametric and non-stochastic index used to measure productivity change between any two periods t and t+1. I will assume that countries can not alter their input endowment, and therefore I will adopt an output oriented Malmquist index, specified by Farel et *al*. (1994) as follows:

$$M_o\left(X_{t+1}, Y_{t+1}, X_t, Y_t\right) = \left[\frac{D_t(X_{t+1},Y_{t+1})}{D_t(X_t,Y_t)} * \frac{D_{t+1}(X_{t+1},Y_{t+1})}{D_{t+1}(X_t,Y_t)}\right]^{1/2} \qquad (1)$$

$D_{t+1}(X_t, Y_t)$ represents the output distance from the period t observation using period t+1 technology. Equation (1) is the geometric mean of two indices. The first is evaluated with respect to period t technology, and the second with respect to period t+1 technology. A value of M_0 greater than 1 indicates a positive TFP growth from period t to period t+1, while a value less than 1 indicates a decline.

Farel *et al.* (1994) show that equation (1) can be rewritten as follows:

$$M_o\left(X_{t+1}, Y_{t+1}, X_t, Y_t\right) = \frac{D_{t+1}(X_{t+1},Y_{t+1})}{D_t(X_t,Y_t)} * \left[\frac{D_t(X_{t+1},Y_{t+1})}{D_{t+1}(X_{t+1},Y_{t+1})} * \frac{D_t(X_t,Y_t)}{D_{t+1}(X_t,Y_t)}\right]^{1/2} \qquad (2)$$

This is nothing but the decomposition into efficiency change (measured by the ratio outside of the brackets) and technological change (represented by the part inside the brackets) components of the output oriented Malmquist index. This is an important property of the Malmquist index. The efficiency change component refers to the movement either closer or further away from the frontier. It reflects the improved ability (or lack thereof) of a country to adopt the available technology. The technical change component captures the effect of a shift in the production frontier as a result of technological advances. It reflects the innovations in the agricultural sector. As with the Malmquist index, values of the efficiency and technical change indices greater than unity indicate improvement in those components.

To address the criticism inflicted on efficiency measures for lacking an error component that allows statistical inferences, Simar and Wilson (1998) propose a bootstrap method[10] to estimate confidence intervals for distance functions used to measure efficiency scores. Simar and Wilson (1999) extend the method to the case of Malmquist and its component indices.

2.2: Data Description

To calculate the Malmquist index and its two components, I use panel data on eight countries over the period 1970 - 2000. The list of the countries included and their socioeconomic characteristics are presented in Table 1 below.

Table 1: List of Countries and Their Key Socioeconomic Characteristics

Country	Rate of Growth of GDP (1970-2000)	Ag. Share of GDP (1970)	Ag. Share of GDP (2000)	Pop. Growth Rate (1970-2000)	% of Ag. Pop (1970)	% of Ag. Pop (2000)
Burkina Faso	3.909717	31.35565	28.99079	2.532828	91.98724	92.20687
Chad	1.667966	39.67878	42.3142	2.660306	92.30769	75.23126
Gambia	3.801289	34.14508	35.79625	3.402348	86.9936	78.95137
Guinea-Bissau	2.376156	47.45552	56.43837	2.361327	89.21233	82.86969
Mali	2.769586	66.02327	41.56936	2.144399	92.63487	80.99081
Mauritania	1.985148	29.27267	27.64791	2.373153	84.31062	52.93006
Niger	0.944309	64.87511	37.83974	2.909353	92.74035	87.64217
Senegal	2.37537	25.33876	19.1419	2.67388	82.7066	73.91472

I use one output and five input variables. The agricultural output is the quantity of agricultural production measured in millions of 1999-2001 international dollars. Labor is the total of economically active agricultural population in thousands; agricultural land, measured in thousands of hectares, is the sum of arable land and permanent cropland; fertilizer is the quantity of fertilizer in metric tons of plant nutrient consumed in agriculture; machinery is the number of agricultural tractors in use. Livestock input variable is the cow-equivalent livestock units of three categories of animals. The categories are: horses, cattle and camels. Following Hayami and Ruttan (1985), the conversion factors are: 1.0 for horses, 0.8 for cattle, and 1.1 for camels.

All the data are derived from the Food and Agricultural organization of the United Nations (FAOSTAT).

Table 2: Descriptive Statistics

Variable	N	Mean	S.D.	Max	Min
Crop Output	264	64.82	22.35	118.64	24.50
Livestock output	264	848950	599579	2544237	30012
Land	264	2954.63	3534.3	145000	130
Labor	264	2069.40	1457.33	5161	210
Tractors	264	415.83	616.08	2600	13
Fertilizers	264	9056.80	11707.35	50238	100
Temperature	264	26.82	1.40	29.40	21.33
Precipitation	264	555.19	387.91	1755.34	67.08
Livestock input	264	2435887	1617283	6032300	185000
Irrigation	264	3.43	4.59	25.00	0.13

The summary statistics of the data used in the computation of the Malmquist index is presented in Table 2. The table indicates large variations in the output as well as the input variables across countries[11].

After calculating the productivity index and its components, my next step is to examine factors explaining the debated agricultural productivity in Africa with particular emphasis on Sahelian countries and persistent drought. Based on past studies, the explanatory variables include such factors as institutions (Fulginiti *et al*. 2004), macroeconomic policies (Jaeger, 1991; Block, 1995;

Towsend and Thirtle, 1998; Thirtle, Lin and Piesse, 2002; Alauddin, Headey and Rao, 2004), agricultural policies (Pratt and Yu, 2008), and environmental variables (Mendelsohn et *al*, 2000; Kurukulasuriya *et al.* 2007; Kabubo-Mariara and Karanja, 2007). This study concentrates on the effects of drought and temperature on agricultural productivity. The rainfall variable used in this study is a 6-month SPI (standardized precipitation index) which indicates the severity of a wet and a dry spell.[12] To the best of my knowledge, this paper is the first to compute and include SPI to study the impact of precipitation on agricultural productivity. This is an improvement over previous studies that used a dummy variable[13] to account for drought (Roncoli et *al*. 2001; Little *et al*. , 2004) or assumed without accounting for it the role of weather on agricultural productivity (Block, 1995). However, unlike this paper, the objective of the previous studies is not to focus on the impact of drought.

Temperature is the second variable used to account for climate conditions. Well respected agronomic studies[14] have documented the relationship between temperature and crop yields. For example, based on a field study in the Philippines, Peng *et al* (2004) find that for each 1°C increase in growing-season minimum temperature, grain yield decreases by at least 10 percentage points.

For the purpose of this study, I use average temperature during the growing season which spans from May to October.

The data on precipitation and temperature are from ARTES (Africa Rainfall and Temperature Evaluation System).

The role of good governance in agricultural productivity has been established in the literature (Lio and Liu, 2008). Following Fulginiti *et al* (2004), the number of years since independence is included to account for the institutional factors.[15] The number of years since independence is collected from the Central Intelligence Agency world factbook.

The investment share in GDP, a proxy for macroeconomic policy, is derived from the online World Development Indicators.

According to Pratt and Yu (2008), agricultural policy reform is one of the two key factors behind the improved performance of Sub-Saharan Africa's agriculture. Their policy change indicator is an index adapted from Cleaver and Donovan (1995). Their index takes only two values: 1 and 4, with 1 indicating best policy. I used a modified policy index to account for performance in agricultural policy reforms. I construct the policy index using the annual growth rate of fertilizer consumption.[16] The index takes on the value of 1 if a country has a negative fertilizer consumption growth, a value of 2 if the growth rate if positive but less than 100 %, and a value of 3 if fertilizer consumption has increased by more than 100 % from one year to the next.

Also, I include in the regressions a time trend to capture the effect of technological progress. I use the percentage of irrigated area in total land variable to measure irrigation, a proxy for land quality. To account for the size of a country, I use the gross domestic product. Lastly, given that the aforementioned macroeconomic expenditures may not have an impact on agriculture if they are biased toward the urban sector (Alauddin et al., 2004; Bezemer and Headey, 2008), I include the share of urban population as a measure of urban bias. The last two variables are consistently statistically insignificant in all the regressions, so I drop the share of urban population from the regressions and I substitute GDP for per capita GDP, a proxy for income.

2.3: Empirical Models

Empirical evidence based on the growth of input and output reveals that the dynamic of agriculture in Sahel is hardly explained by the traditional input to production usually discussed in the literature. Both output growth and precipitation have been very volatile compared to input growth during the period from 1970 to 2000. In the face of this highly volatile precipitation pattern, one should ask whether agricultural sector can be sustained in Sahel. Pratt and Yu (2008) convincingly argue that in the face of resource constraints and increased pressure from rural population growth, the only possible way for agriculture to be sustained is through total factor productivity growth. In the next two paragraphs, I will make use of linear panel fixed effects and probit estimations to examine the factors behind the changes in total factor productivity in Sahel.

2.3.1: Fixed Effects:

I use the fixed effects because the fixed effect estimator is consistent when the unobserved effects are correlated with the independent variables, but the random effect is not. Another raison for using the fixed effects model is that it further allows me to estimate a unit-specific effect for each of the eight countries in this study. Also, the fixed effects model will allow me to purge the effect of time invariant controls and other non-included time invariant factors from the model (Barrios et al. 2003). In addition to the variables presented in the data section, I also include some lags of drought and precipitation, reasoning that past drought events can worsen land degradation[17], and that land degradation is linked to productivity (Wiebe, 2003).[18]

I develop the following analytical framework to study the impacts of droughts on agricultural productivity:

$$TFPit = \Theta i + \Theta rt + Xit\beta it + \sum_{j=0}^{L} \delta jPit - j + \sum_{k=0}^{N} \lambda kTit - k + \varepsilon it \qquad (3)$$

Where TFP is the growth of total factor productivity, Θi are country fixed effects, Θrt are time fixed effects, X includes a constant term, a time trend, per capita GDP, and measures of agricultural policy, the number of year since independence, investment share in GDP, and percentage of irrigated area in total land. (See the data appendix for details). The variable p is a

6-month SPI (as explained in Boubacar, 2008), and T is the annual average temperature during the growing season.

2.3.2: Probit Model

The results of the fixed effects model explain the impacts of drought on the mean of TFP during the period of this study for the sampled countries. Disaggregated country level Malmquist index results indicate that more than half of the TFP values are less than unity. In other words, a declining TFP has been the norm rather than the exception in Sahel. In the context of continued population growth, food insecurity, and the predicted climate change, policymakers would like to identify factors behind the observed productivity losses, and to take appropriate mitigation strategies. From a policy perspective, I believe that a marginal effect is more instructive than an average effect.

Additionally, from a theoretical viewpoint, some authors (Lobell, Cahill and Field, 2007; Deschenes and Greenstone, 2007) raise the concern that the relationship between climate variables and crop production may be non-linear. For that reason, they include linear and quadratic terms of their variables of interest in their model specification (see for example models based on the Ricardian approach).

Finally drought is a risk to agricultural production. Thus, the existence of risk warrants the use of a probabilistic approach to quantify the impacts of climate change in agricultural productivity.

Considering the aforementioned reasons, equation (3) can be reformulated to simultaneously capture the non-linear relationship between climate variables and agriculture and allow it to account for the marginal position around a TFP of unity.

The idea is best assessed using a probit model as follows

$$\mathrm{P}(\mathrm{TFP}_{\mathrm{it}}^{*} < 1 \vdots Z) = \mathrm{P}(\mathrm{Z} < (Xit\beta it + \sum_{\mathrm{j}=0}^{\mathrm{L}} \delta\mathrm{jPit} - \mathrm{j} + \sum_{k=0}^{N} \lambda k T it - k \ )) \quad (4)$$

Where Z includes T, P and all the variables in X; and

$$\text{TFP}_{\text{it}}^{*} = \begin{cases} 1, & TFP \text{ change} < 1 \\ 0, & otherwise \end{cases} \quad (5)$$

I begin by estimating (3) and (4) with no lags, in order to test the hypothesis that climate does not affect productivity. The test is described as follows:

For drought, H_0: $\delta_0 = 0$ and H_a: $\delta_0 \neq 0$ (6)

For temperature, H_0: $\lambda_0 = 0$ and H_a: $\lambda_0 \neq 0$ (7)

If statistical evidence suggests that the null hypothesis is rejected, then I should pursue the regressions including current and lag climate variables.

2.4: Panel Unit Root Test

It has been argued that past studies arbitrary assume that the series involved in estimations are integrated of order zero. To break from the traditional assumption, I test the presence of unit root for each variables included in the regressions. Each series found not to be integrated of order zero must be differenced before the estimation. This unit root test is based on relatively new tests using a panel structure of all cross-section units. I carry out the panel unit root tests following Im, Pesaran and Shin (2003). The results suggest that I do not have enough statistical evidence to reject the null hypothesis that Investment, Irrigation and per capita GDP variables are integrated of order one. Therefore, I must difference those three series before proceeding to the regressions.

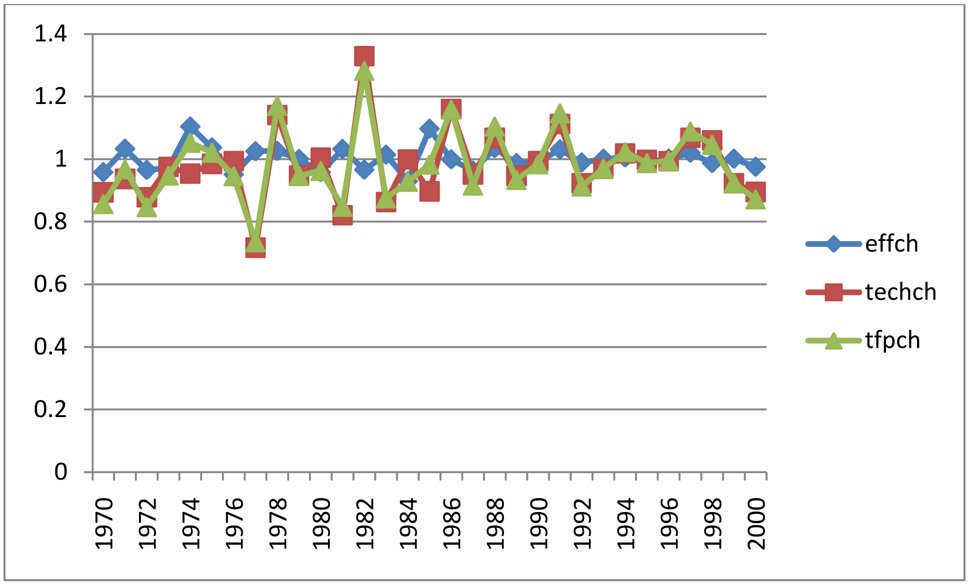
III: Results:

3.1: Malmquist Total Factor Productivity Index and its Decompositions:

Even though the focus of this paper is to study the impacts of change in precipitation and temperature on agricultural productivity, it will be insightful to first analyze how TFP has evolved in Sahel since 1970. Figure 2 shows the evolution of the growth rates of TFP and its component indices. With few exceptions, the variations of technical change closely mimic that of

TFP change. The trend is characterized by erratic fluctuations with respect to TFP change and technical change.

Figure 2: Trend in TFP change and its Components over time (Sahel)



In contrast, Table 3 suggests an overall positive trend in the region with respect to technical efficiency change. On the average, the weighted technical efficiency has increased by 0.63 percent per year for the entire set of countries. Yet, the performance varies across countries. For example Burkina Faso and Senegal have experienced an average change above the regional average, while Guinea Bissau, Mauritania and Niger show virtually no change in efficiency. On the average, technical efficiency seems not to be an obstacle to Sahelian countries in achieving high performance in agricultural productivity. Pratt and Yu (2008) reach a similar conclusion as well.

The average technical change for all the eight countries and the weighted average value for the regions are reported in the third column of Table 3. Overall, the results point to a regression: a weighted average decline of 0.99 percent annually for the region. However, countries like Guinea Bissau and Niger have experienced a relatively big increase in technological change.

The first column of Table 3 reports the average Malmquist productivity index for each country, and the weighted average index for the region. It appears that the weighted average Malmquist index has declined by 0.947 percent annually. Recall that, from equation 2, TFP can be increased by either improving technical efficiency or technological level, or both. But the analysis of the component measures of TFP change reveals that technical efficiency has not improved enough to offset the decline in technological change. In order words, for the region, agricultural productivity is seriously impeded by the lack of technological change. In explaining the causes of productivity growth differential between the tropical regions (which are technologically deficient) and the temperate regions (innovators), Bloom and Sacks (1998) argue that agricultural technologies do not transfer well across ecological zones.

Only three countries (Gambia, Mali and Senegal) report gains in productivity. Additionally, I identify three countries as the worst performers in that they record not only a dismal productivity change, but also a negative trend in both component measures of TFP change. Those countries are Guinea Bissau, Mauritania and Niger. In fact, they are the same countries that exhibit no changes in efficiency. The remaining two countries (Burkina and Chad) that experience declines in productivity show an improvement in efficiency, but not large enough to offset the loss in technological change. A similar pattern is also observed at the regional level with the weighted average results. There is no country with concomitantly a productivity gain and an improvement in both efficiency change and technical change. These results of negative trends are in sharp contrast with the findings by Lusigi and Thirtle (1997) who report an improvement in both technical change and efficiency change for the 47 Sub-Saharan African countries included in their study sample. The results of Table 3 offer an insight into the state of the agricultural sector in Sahel. The poor agricultural productivity performance spins from the lack of innovation rather than the adoption of the available technology.

Table 3: Average rates of Malmquist TFP change and its Components

Countries	Total factor Productivity Change (TFPC)			Efficiency Change (EC)			Technological Change (TC)		
	Lower Bound	TFPC	Upper Bound	Lower Bound	EC	Upper Bound	Lower Bound	TC	Upper Bound
Burkina	0.9299	0.9784	1.0298	1.00793	1.0079	1.01593	0.9267	0.9841	1.0316
Chad	0.9424	0.9849	1.0437	0.99623	1.0021	1.00413	0.9259	0.9836	1.0307
Gambia	1.0119	1.0206	1.1206	0.99482	1.0014	1.00271	0.9240	0.9827	1.0286
Guinea Bissau	0.9492	0.9885	1.0512	0.99213	1	1	1.0195	1.0322	1.1349
Mali	0.9874	1.0082	1.0935	0.99889	1.0034	1.00681	0.9198	0.9804	1.0239
Mauritania	0.8394	0.9296	0.9296	0.99213	1	1	0.8433	0.9388	0.9388
Niger	0.8952	0.9599	0.9914	0.99226	1.0001	1.00013	1.0450	1.0450	1.1633
Senegal	1.0295	1.0295	1.1401	0.8558	1.0217	1.2247	0.9078	0.974	1.0106
Sahel	0.9531	0.99053	1.0554	1.0046	1.0063	1.0126	0.9381	0.9901	1.0443

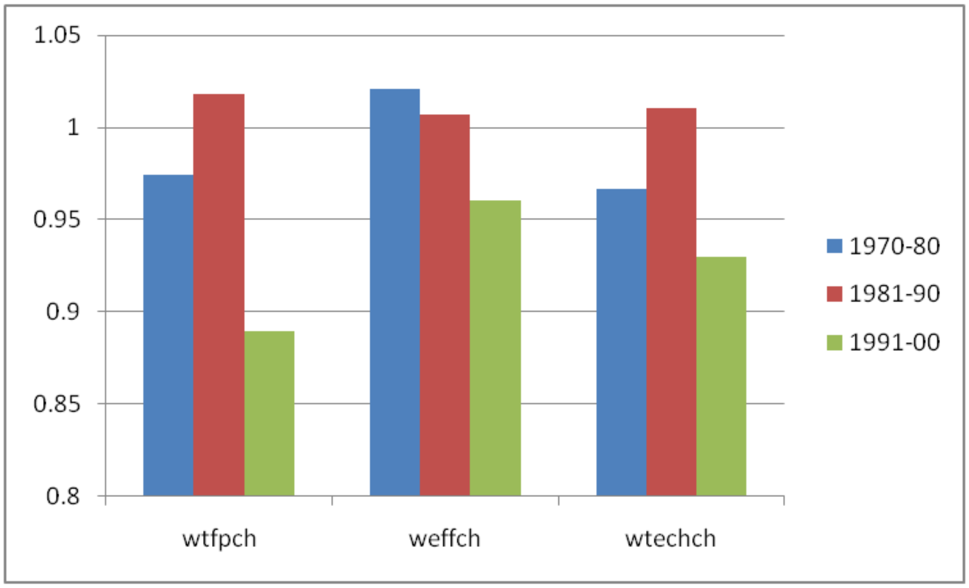
With respect to TFP change, my results corroborate the findings by Trueblood and Coggins (2003) who report productivity losses in five of the six Sahelian countries included in their study sample. Additionally Nin and Yu (2008), in analyzing the role of restrictions on shadow price used in DEA estimates, find Sub-Saharan Africa to perform well. However, on a country-by-country analysis, their result reveals that 5 of the 7 Sahelian countries in their study show a decline in TFP change regardless of the approach used. Along the same line, Coelli and Rao (2005) use the Malmquist index approach to study the agricultural productivity in 93 developed and developing countries. Three of the four Sahelian countries included show a decline in agricultural productivity from 1980 to 2000. Moreover, the country with the least TFP growth and technical change is a Sahelian country. In contrast, other studies have found a positive TFP growth. For example, Pratt and Yu (2008) find an improvement in Sub-Saharan African agricultural productivity. Their results suggest an average of 1.80 percent growth from 1964 to 1983, with 1972 and 1983[19] being the worst years. According to the authors, the period of 1984 to 2003 was characterized by an unprecedented growth of 3.2 percent per annum. But, their regional results show evidence that Sahel is the least performer amongst the groups. They attribute this performance to improved efficiency in the production process and to a better policy environment implemented in most African countries since the mid-80s.

Grouped by decade, TFP change and its component indices are presented in Figure 3. It appears that the region has experienced a productivity loss in the 1970s (2.55 percent), a rebound in the 1980s (1.82 percent), and a substantial decline in the 1990s (11.03 percent). Similarly, Block (1995) finds a significant improvement in productivity during the 1980s.

A decadal analysis of the African agricultural productivity growth by Fulginiti *et al*. (2004) shows a slight difference in the pattern observed in this study. For example, they find a negative growth in the 1970s (-0.32), a rebound in the 1980s (1.29) and an even higher performance in the 1990s (1.69). The mixed results from a decadal analysis can also be found in the study by Pratt and Yu[20] (2008). They find a negative TFP growth in 1964-73 (-0.99) and 1974-83 (-0.55) followed by two decades of improvement in 1984-93 (0.89) and 1994-2003 (1.48).

I highly suspect the worst performance observed during the 1990s to be indicative of the cumulative effects of the 1980s' drought. This hypothesis is tested using probit regressions discussed in the next section.

Figure 3: Average Annual TFP changes and its Components by Decades



3.2: The Probit Results:

In the words of Edward Frees (2004, page 11), "longitudinal data models in and of themselves are insufficient to establish causal relationships among variables".

The Malmquist productivity indices, as discussed in section 3.1, highlight the existence of productivity differential both across and within countries in Sahel. Moreover, the values of TFP growth less than unity appear to be the characteristics of the output. Thus, with a skewed distribution, the analysis of the mean value of TFP change (done with TFP change as a continuous dependent variable in the case of linear fixed effects in sub-section 2.3.1) is not appropriate. Additionally, during those years or to those countries on the edge of efficiency (TFP growth marginally greater or less than unity), a slight difference between a drought year and a wet year would significantly be pivotal. The question that one may ask is what are the countries' characteristics that could explain the difference in agricultural productivity performance in Sahel? And part of the motivation of this paper is to investigate how changes in climate variables affect agricultural productivity. Specifically, my aim is to explain the extent to which persistent droughts have been a causal factor decreasing agricultural productivity in Sahel. Angrist (1999) convincingly argues that causal relationships (with dichotomous dependent variable), unlike descriptive analyses (with continuous dependent variable), not only answer counterfactual questions, but are more of value for predicting the effects of changing circumstances or understanding the past. For the specific case of Sahel, the past has been colorful in severe droughts, and this environmental state is predicted to continue in the future because of global warming (numerous reports of IPCC).

For all the aforementioned reasons, my preferred specification is the probit regressions.

For robustness check, I estimate several specifications of equation (4).

I begin by estimating equation (4) with only drought and its lags as climate variables.

The results are presented in Table 4. It appears that agricultural policy, investment share in GDP, the number of years since independence and the time trend variables all have significant influence on TFP change. A 1 percent increase in investment share of GDP is associated with 93 percent chance of TFP growth being greater than one. This strong relationship between investment and productivity is particularly interesting. The positive impacts of investment on economic growth have well been documented in growth literature. As pointed out by Rao *et al* (2004), government expenditures in education, health, provision of infrastructure, agricultural research and development have the potential to improve productivity through better adoption of existing technology and more access to new technology. With respect to this paper, the point made by Rao *et al.* is reinforced by the significance and the magnitude of the coefficient on the time trend variable, a proxy for technological change. Not surprisingly, the results of TFP and its components reveal that the challenges are more of technological constraints than efficiency issues.

Following Fulginiti *et al* (2004), I use the number of years since independence as a proxy for institutions. My results indicate that the longer is the independence period, the higher is the probability that the growth rate of TFP falls below 1. In contrast, Fulginiti *et al* (2004) find that productivity tends to decrease during the first 12 years of independence, and increases thereafter (their sample includes Nigeria and Tanzania, two countries with large agricultural base, and whose inclusion biases the productivity of SSA, as shown by Nin and YU (2008). Also, their sample includes countries like Ghana that are believed to be “long-standing reformers” (Bloom and Sachs, 1999). Additionally, using agricultural output as their measure of productivity and an aggregate indicator of governance as their proxy for institutions, Lio and Liu (2008) find support for better governance in generating higher agricultural productivity.

The irrigation variable is not statistically significant. This is not surprising as irrigation and investment may be correlated. Investment, here, refers to public investment and irrigation is also a form of investment by the government in the rural areas where most of the poor farmers live. Additionally, as pointed out by previous studies, and also supported by Table 2, irrigation is not widespread in Sahel, and therefore one can argue that it has a minimum (if any) impact on agricultural productivity.

The coefficient on the drought variable is negative and statistically significant. Though, the coefficient should be interpreted with caution because drought index takes positive and negative values centered on zero. A positive SPI indicates wet spells, and a negative SPI means drought. My results show a quite significant positive effect of precipitation on productivity. Block (1995) has partly attributed the African agricultural recovery observed in the 1980s to good weather conditions. In contrast, Fulginiti *et al.* (2004) do not find drought to have a negative impact on agricultural productivity in SSA. Their sample includes arid, semi-arid and wet regions of Africa. Scientific evidence (Bates *et al.* 2008) suggests that global warming will intensify the occurrence and the severity of droughts in Sahel.

Table 4: Marginal Effects of Drought and its lags on P(TFP change < 1)

Variables	Drought	1 lag	2 lags	3 lags
Constant	0.150 (1.168)	0.213 (1.622)	0.218 (1.591)	0.222 (1.637)
Time Trend	-0.022 (-2.526)**	-0.0247 (-2.772)*	-0.0247 (-2.762)*	-0.0248 (-2.765)*
Income	-0.0006 (-1.122)	-0.0006 (-1.0195)	-0.0006 (-0.998)	-0.0006 (-0.991)
Ag Policy	-0.0667 (-1.314)	-0.0495 (-0.974)	-0.0502 (-0.964)	-0.0499 (-0.971)
Independence	0.0135 (1.771)***	0.0145 (1.879)***	0.0145 (1.878)***	0.0147 (1.889)***
Investment	-0.0284 (-1.724)***	-0.0318 (-1.768)***	-0.032 (-1.770)***	-0.032 (-1.780)***
Irrigation	-0.033 (-0.728)	-0.0309 (-0.590)	-0.0313 (-0.599)	-0.0333 (-0.622)
Drought	-0.115 (-2.657)*	-0.1421 (-3.161)*	-0.142 (-3.155)*	-0.1414 (-3.142)*
L1-drought		0.177 (4.027)*	0.176 (3.976)*	0.176 (3.958)*
L2-drought			0.0066 (0.151)	0.0056 (0.118)
L3-drought				0.0145 (0.346)

Notes: *, ** and *** indicate that the parameter is significant at 1%, 5% and 10% levels, respectively. The t-ratios are in parenthes.

For what will follow, I consider models with lags in order to grasp the dynamics of the interaction between droughts and agricultural productivity.

In doing so, I will examine not only the current effects but also the carryover effects of climate on productivity. The length of lags to include will be determined by a "tatonnement process", as there is no prior study of distributed lag models with an application to drought and productivity. With respect to drought, beyond the first year, the coefficient estimates of the lag variables are not statistically significant. This means that rainfall conditions in a giving year will affect the productivity during that year and the following year. With one lag included, the cumulative effect of drought is positive. This means that TFP will fall with two or more years with drought. In a second alternative specification, I estimate equation (4) with temperature and its lags.

Table 5: Marginal Effects of Temperature and its lags on P(TFP change < 1)

Variables	Temp	1 lag	2 lags	3 lags	4 lags
Constant	0.758 (0.469)	-0.0882 (-0.096)	0.677 (0.396)	0.219 (0.115)	0.524 (0.303)
Time Trend	-0.026 (-2.68)*	-0.0220 (-2.43)**	-0.0244 (-2.44)**	-0.0228 (-2.22)**	-0.0243 (-2.41)**
Income	-0.0007 (-1.282)	-0.0007 (-1.320)	-0.0007 (-1.360)	-0.0008 (-1.398)	-0.0008 (-1.377)
Ag Policy	-0.0833 (-1.674)***	-0.0723 (-1.442)	-0.0673 (-1.330)	-0.0728 (-1.426)	-0.0752 (-1.473)
Independence	0.0161 (1.752)***	0.0119 (1.395)	0.0147 (1.472)	0.0131 (1.250)	0.0143 (1.432)
Investment	-0.0295 (-1.8.15)***	-0.029 (-1.80)***	-0.0307 (-1.90)***	-0.0327 (-2.03)**	-0.0324 (-2.03)**
Irrigation	-0.0401 (-0.886)	-0.0288 (-0.618)	-0.0307 (-0.641)	-0.0307 (-0.629)	-0.0245 (-0.502)
Temperature	-0.029 (-0.546)	-0.106 (-1.581)	-0.0752 (-1.025)	-0.128 (-1.61)***	-0.111 (-1.388)
L1- Temp		0.119 (1.83)***	0.176 (2.223)**	0.156 (1.97)***	0.188 (2.252)**
L2- Temp			-0.117 (-1.58)***	-0.171 (-2.13)**	-0.161 (-2.01)**
L3- Temp				0.144 (1.83)***	0.172 (2.11)**
L4-Temp					-0.0982 (-1.254)
L5-Temp					

Notes: *, ** and *** indicate that the parameter is significant at 1%, 5% and 10% levels, respectively. The t-ratios are in parentheses.

Table 5 shows the results of the impact of temperature on TFP growth. Statistically, current temperature has no effect on productivity. This is an indication that the main cultivated crops in Sahel (Millet, sorghum) are heat tolerant. Previous studies have shown mix results on the impact of temperature on agriculture. For example, exploring the interaction between climate, water and agriculture, Mendelsohn and Dinar (2003) find that warming is slightly harmful to US farmers; but with climate variance terms, warming turns slightly beneficial.

The coefficient estimates on lag one, lag two and lag three are statistically significant with a cumulative strong effect on productivity. In particular, the cumulative effect of a 1° C increase in temperature is associated with an increase in the probability of TFP growth falling by 12.94 percentage points after three years.

The separate effects of drought and temperature on productivity persist even when both climate variables are simultaneously included in the regression (See Table 6 below). However, temperature appears to have longer-lasting effects than drought. My results contrast the findings by Dell et *al* (2008) who find that precipitation has no effects on growth rates.

Table 6: Marginal Effects of drought, Temperature and their lags on P(TFP change < 1)

Variables	**(1)** **No lag**	**(2)** **Lag 1**	**(3)** **Lag 2**	**(4)** **Lag 3**
Constant	0.860 (0.603)	-0.453 (-0.280)	0.544 (0.319)	-0.0471 (-0.0528)
Time Trend	-0.0241 (-2.490)**	-0.0228 (-2.247)**	-0.0262 (-2.582)**	-0.0245 (-2.596)*
Income	-0.0006 (-1.100)	-0.0006 (-1.049)	-0.0006 (-0.976)	-0.0006 (-0.991)
Ag Policy	-0.0669 (-1.322)	-0.0473 (-0.924)	-0.0388 (-0.752)	-0.0480 (-0.908)
Independence	0.0162 (1.732)***	0.0120 (1.771)***	0.0159 (1.587)	0.0139 (1.603)***
Investment	-0.0291 (-1.745)***	-0.0312 (-1.733)***	-0.0338 (-1.876)***	-0.0365 (-2.016)**
Irrigation	-0.0319 (-0.708)	-0.0293 (-0.547)	-0.0312 (-0.562)	-0.0333 (-0.560)
Temp	-0.0268 (-0.500)	-0.0018 (-0.0238)	0.0457 (0.559)	-0.0097 (-0.0832)
Drought	-0.114 (-2.648)*	-0.140 (-3.048)*	-0.1643 (-3.409)*	-0.169 (-3.372)*
L1-Temp		0.0268 (0.403)	0.115 (1.330)	0.0839 (0.908)
L1-drought		0.176 (3.842)*	0.168 (3.572)*	0.183 (3.740)*
L2-Temp			-0.174 (-2.133)**	-0.263 (-2.886)*
L2_ drought			0.0294 (0.660)	0.0450 (0.982)
L3-Temp				0.198 (2.229)**
L3-drought				-0.0248 (-0.545)
LLF	-158.96	-150.40	-148.05	-145.26
Pseudo R2	0.0709	0.1209	0.1347	0.1510

Notes: *, ** and *** indicate that the parameter is significant at 1%, 5% and 10% levels, respectively. The t-ratios are in parentheses.

IV: Drought and Economic Growth in Sahel:

The development literature evokes several factors to account for a nation's economic growth. Using Bayesian averaging of classical estimates, Sala-i-Martin *et al* (2004) investigate the explanatory power of 67 variables historically included in the growth regressions. Their sample covers a cross section of 88 countries over the period from 1960 to 1996. They find that 18 of the 67 variables are "significantly and robustly partially correlated with long-term growth", and that 3 other variables are "marginally related". And furthermore, their results identify 3 variables, namely the relative price of investment, the initial level of real GDP per capita and primary school enrolment, which show the strongest correlation with long term growth.

Recent debate has identified the combination of both domestic and external factors to account for the causes of Africa's growth disaster. But, as pointed out by Barrios et *al* (2003), the evidence of their importance is mixed. Nonetheless, "there should be no doubt that the worst economic disaster of the XXth century is the dismal growth performance of the African continent…It is dismal in absolute terms, but it is worse if we take into account that, during the same period, the rest of the World has been growing at an annual rate of close to 2 percent", Artadi and Sala-i-Martin (2003).

Although there is evidence in support of the explanations put forward to account for Africa's economic debacle, I strongly believe, along with Barrios, Bertinelli and Strobl, (2003) and Bloom and Sachs (1998), that the distinct climatic conditions in most African countries have put solid obstructions to their economic growth. The immediate consequences of the harsh climatic conditions are a low agricultural productivity, high diseases and low life expectancies (Bloom and Sachs, 1998).

This section reviews and discusses the evidence of the impact of drought on Sahelian countries' economic growth over the period from 1970 to 2000. The timeframe is long enough to give an overview of the relationship between agricultural productivity and economic growth before, during and after drought years in some heavily agrarian countries. Benson and Clay (1998) argue that the severity of the impacts of drought depends on the economic environment. In an economy of subsistence with rain-fed agriculture and an almost inexistent infrastructure as is the case in the Sahel, the impacts of drought on the economy may be particularly devastating. For example, GDP growth did not recover from the 1970s as a consequence of drought in Sahel (Sanders *et al.* 1996). The situation is seriously alarming because of the importance of the agricultural sector in the overall economy. For instance, Pinstrup-Andersen, Lundberg and Garrett (1995) show that through the multiplier effects, each additional dollar from farm income adds $ 2 to $ 3 to the overall economy in Sub-Saharan Africa. As I stress it earlier, in Sahel, agriculture depends heavily on rainfalls, and many authors[21] (Bloom and Sachs, 1998; Collier and Gunning, 1999; O'Connell and Ndulu, 2000) suggest that the decline in precipitations may have played a key role in the economic debacle of the region. Thus, an ill agricultural sector will drag down the entire economy.

To alleviate poverty, it is important to both accurately identify the target and use the appropriate mechanisms. I do believe that demographic and economic factors as discussed in previous studies do matter in explaining Africa's low economic performance. However, I put more emphasis on climate variables for a number of reasons. For one thing, little will be gained in just revising what have been presented in past studies. And more importantly, as pointed out by Bloom and Sachs (1998), Africa's natural environment (climate, soil, and diseases) is at the forefront of all the obstacles to growth faced by the continent.

4.1: Data and Model

Two distinct strategies have been traditionally pursued when estimating growth regressions. The first approach, also known as "Barro-type", consists of cross-section regressions of GDP growth rates on initial values or long- term averages of some potential regressors (Barro, 1991; Bloom and Sachs, 1998); and the second approach is based on panel regressions (Grier and Tullock, 1989; Easterly and Levine, 1997). Both approaches have their merits and their shortfalls. For example, cross-section regressions permit the inclusion of larger country samples and a comprehensive set of explanatory variables. On the other hand, panel estimations control for omitted variables and unobservable country-specific effects, which is not possible with cross-section models.

My sample includes eight countries (see Table 1), using data spanning from 1970 to 2000. Thus, I find the advantages of using panel estimations more appealing. The empirical framework is described as follows:

$$g\text{it} = \Theta i + \Theta rt + Xit\beta it + \delta dit + \lambda Tit + \alpha TFPit + \varepsilon it \quad (8)$$

With i = 1, 2, …8 and t = 1970, …2000

Where g_{it} is the growth rate of real per capita GDP (RPGDP), Θi are country fixed effects, Θrt are time fixed effects, d_{it} is the 12 month-SPI, T_{it} is the average annual temperature, TFP_{it} is the TFP change from year t-1 to year t, X_{it} includes control explanatory variables such as the price of investment goods (following Sala-i-Martin *et al* , 2004), and institutional variables (war and polity 2, following Collier and Gunning, 1999 to account for policy dispersion within Africa), and εit is an error term.

One can argue that the burden of the struggle is mostly borne by the agricultural population that happens to be the rural population. According to the International Fund for Agricultural

Development (2001), 75 percent of the poor live in rural areas, and more than 60 percent will continue to do so in 2025. For the poor in developing countries, agricultural is the primary source of employment and daily livelihood. To capture the incidence of climate change on rural populations, equation (8) is re-estimated using the growth rates of real per capita agricultural GDP (RPAGDP) as the dependent variable.

The data on real per capita GDP and the price of investment goods are derived from the Penn World Table. The productivity variable is the agricultural Malmquist TFP change computed in section 2 above. The RPAGDP data are derived from the online World Development Indicators. The SPI drought index is calculated using monthly precipitation data from ARTES. The temperature variable is also from ARTES.

4.2: Results

Using fixed effects robust estimation, I first regress the annual growth rates of real per capita GDP on temperature and drought. The results are shown in the first column of Table 7 – Panel A. Overall, the model has a good explanatory power, and explains a very large portion of the dependent variable. From the individual results piece-wise, it appears that climate variables have significant effects on economic growth in Sahel. In particular, drought is positively and statistically related to economic growth. A 1 unit improvement in the drought index in a given year increases the rate of real per capita GDP growth in that year by 2.32 percentage points. This result echoes previous findings on the beneficial effects of precipitation on economic activities, especially in countries dependent on rainfall. For example, Barrios et *al*. (2003) find precipitation to be statistically significant only in the sample of African countries. In contrast, Dell et *al*. (2008) find no statistical evidence of the impact of precipitation on GDP growth in neither poor nor rich countries.

The coefficient estimate on temperature variable is negative and statistically significant. A 1° C higher temperature produces a 0.962 percentage point reduction in real per capita GDP growth, ceteris paribus. Almost a similar magnitude is found by Dell et *al* (2008) for poor countries. In Sahel, a tropical region per excellence, temperature is almost always very high, with little difference between the minimum and the maximum (see Table 2). Bloom and Sachs (1998) convincingly argue that Africa's disadvantageous climatic conditions (tropical regions) are the main cause of its impoverishment.

For robustness check, I also include a set of control variables, as explained in the data section. As mentioned above, one goal of this paper is to investigate the impact of drought and temperature on the economic growth in Sahel, and not to re-examine the previously discussed theories in development economic. Hence, the results regarding the control variables are not discussed here, but reported in the second column of Table 7- Panel A, where the results of the variables of interest are also reported. It appears that, of the control variables, only war is statistically significant, and with a very large negative effects on growth. One should also notice the estimates of my variables of interest remain stable both in terms of magnitudes and statistical significance.

Table 7- Panel B re-considers the specification of equation 9 using the growth rates of real per capita agricultural GDP (RPAGDP) as the dependent variable. Three observations stand out from comparing the results in Panel B to those in Panel A.

First, the effects of climate variables are more pronounced on RPAGDP than RPGDP. This result confirms and strengthens the hypothesis that climate change has a devastating impact on the agricultural sector in Sahel.

Second, the positive coefficient for TFP change becomes statistically significant, indicating how an increase in agricultural productivity enhances the welfare of rural populations.

Third, this point is common to both results in Panel A and Panel B. It appears that economic (expressed in terms of RPGDP or RPAGDP) is more influenced by changes in precipitation than temperature, ceteris paribus. Specifically, a 1° C higher temperature is associated with 1.25 percentage points lower growth in real per capita agricultural share in GDP. Dell et *al.* (2008) attribute this effect to labor productivity losses. As for precipitation, a 1 unit improvement of the drought index is associated with 3.58 percentage points higher growth in real per capita agricultural share in GDP. This effect may help explain the adverse impacts of persistent droughts in Sahel. This third point is in sharp contrast to the finding by Kurukulasuriya *et al.* (2007) who support that dryland farmers' revenues are more affected by an increase in temperature than changes in precipitation.

Table 7: Economic Growth and Drought Nexus in Sahel

Panel A

Dependent variable: Real Per Capita GDP Growth Rate		
	Coefficients (T-stat)	Coefficients (T-stat)
Drought	2.319 (2.448)**	2.056 (2.314)**
Temperature	-0.962 (-1.909)***	-1.004 (-2.084)**
TFP		1.585 (0.867)
Investment		0.00134 (0.252)
War		-4.238 (-2.582)**
Polity2		0.0715 (1.129)
constant	29.778 (2.191)**	30.327 (2.400)**
R-squared	23.86 %	30.70 %
F-Stat (P-value)	1.671 (0.0121)**	2.102 (0.0003)*

Panel B

Dependent variable: Growth Rate of Real Per Capita Agricultural Share in GDP		
	Coefficients (T-stat)	Coefficients (T-stat)
Drought	3.85 (4.40)*	3.588 (4.19)*
Temperature	-1.18 (-1.86)***	-1.253 (-2.02)**
TFP		5.30 (1.72)***
Investment		0.0605 (0.311)
War		-3.77 (-2.17)**
Polity2		-0.109 (-0.98)
constant	33.20 (1.96)***	30.15 (1.92)***
R-squared	8.83 %	13.05 %
F-Stat (P-value)	2.56 (0.0079)*	2.70 (0.0014)*

Notes: *, ** and *** indicate that the parameter is significant at 1%, 5% and 10% levels, respectively. The t-ratios are in parentheses.

V: Conclusion

In this paper, the agricultural productivity performance is assessed using a non-parametric Malmquist index. My results show that the performance of Sahel's agriculture has been disastrous. From 1970 to 2000, agricultural productivity has declined at an average annual rate of 0.947 percentage points. However, all the countries do not follow the same pattern in productivity performance. Three of the eight countries stand out as relatively the best performers, meaning that they record a productivity gain. The results of this study corroborate the findings by

Nin and Yu (2008) who also find negative trends in TFP growth with respect to the Sahelian countries included in their paper.

Using a comparable cross-country measure of drought, I provide evidence that precipitation variability is constraining agricultural productivity growth in Sahel. Persistent droughts and increase in temperature have significantly hampered the performance of Sahel's agriculture.

Lastly, I examine the effects of chronic droughts and high temperature on the annual growth rates of real per capita GDP and the annual growth rates of real per capita agricultural GDP in Sahel. My results indicate that the harsh climatic conditions are an impediment to Sahel's economic growth.

Sahel is predicted to experience more droughts in conjunction with the effects of global warming (IPCC, 2001). Therefore, policymakers should take steps to reduce the sensitivity to rainfall of the exposed countries. For example, the agricultural system needs to incorporate more irrigation technique. Alternatively, the path to economic development should drift more towards manufacturing and service sector exports (as suggested by Bloom and Sachs, 1998) rather than the promotion of the agricultural sector.

The results of this study can be used by policymakers and the international community who are looking for ways to address the Sub-Saharan Africa's poverty trap. I highlighted factors that have hindered Sahelian economic performance over the period from 1970 to 2000. The most terrifying part is that scientific evidence predicts that those factors will increase in intensity over years to come. By identifying those factors, this paper provides a giant step capable of developing mechanisms through which policymakers can influence economic growth if so desire. Further work is needed to identify the length of lags of drought and temperature to consider in productivity study.

Endnotes:

[1] Based on 2008 FAO data
[2] The two regions have their own shares of very poor countries where the economic situation is comparable to what is prevailing in Sub-Saharan Africa.
[3] Sahel is part of West African region
[4] Carswell (2000) as cited by Aune and Bationo (2008) noted that agricultural development has three characteristics: Extensification, labor-led intensification and capital-led intensification
[5] IPCC stands for Inter government Panel on Climate Change
[6] The first important point of Table 1 is that the share of agriculture in GDP remains very high throughout the period of this study, with the exception of the two recently oil-producing countries (Chad and Mauritania).

[7] And most certainly not from 1981 to 1984
[8] Measures as precipitation net of evapotranspiration (evaporation and transpiration during photosynthesis)
[9] I also run an alternative estimation using real per capita agricultural GDP growth rates
[10] That builds on a bootstrap procedure introduced by Efron (1979)
[11] In general, the growth in output exhibits much more volatility than the growth of input, suggesting the existence of other forces driving the agricultural production besides the traditional input used in the literature.
[12] See Boubacar (2008) for details regarding drought indices.
[13] The problem with a dummy variable is that it represents any other variables not accounted for in the regression. Ideally, more important variable must be included explicitly in the estimation.
[14] See McKeown, A.W.; Warland, J. and McDonald, M.R. (2006) for a throughout review of the agronomic literature on the relationship between temperature and grain yields.
[15] In alternative specifications, I use war intensity variable, collected from Armed Conflicts Version 4, 2008. The variable was consistently statistically insignificant.
[16] Agricultural policy reforms can take the forms of incentives to farmers in order to use high yield-enhancing seeds, increase fertilizer consumption, or access to irrigation.
[17] Wiebe (2003) defines Land degradation as changes in the quality of soil, water, and other characteristics that reduce the ability of land to produce goods and services that are valued by humans.

[18] However, this study does not intent to model the link between land quality and agricultural productivity.
[19] Those two years are remembered as severe drought years in most African countries.
[20] The values reported here exclude Nigeria as its inclusion further magnifies the results.
[21] Of course, those studies do not seek to investigate the issue.

References:

Alauddin, Mohammad; Headey, Derek and Rao, D.S. Prasada (2004), Explaining Agricultural Productivity Levels and Growth: An International Perspective, CEPA Working Paper Series WP022005, University of Queensland, Australia

ARTES: Africa Rainfall and Temperature Evaluation System, Version 1, 2003

Aune, Jens B.; Bationo, Andre (2008), Agricultural Intensification in the Sahel- The Ladder Approach, *Agricultural Systems*, Vol. 98, pp 119-125.

Barrios, Salvador; Bertinelli, Luisito and Strobl, Eric (2003), Dry Times in Africa: Rainfall and Africa's Growth Performance, MPRA Paper No 57505, available online at http://mpra.ub.uni-muenchen.de/5705/1/MPRA_paper_5705.pdf

Barrios, Salvador; Ouattara, Bazoumana and Strobl, Eric (2008), The impact of climatic change on agricultural production: Is it different for Africa?, *Food Policy,* Vol. 33, pp 287–298.

Barro, Robert J. (1991), Economic Growth in a Cross-Section of Countries, *Quarterly Journal of Economics,* Vol. 106, No 2, pp. 407-43.

Bezemer, Dirk and Headey, Derek (2008), Agriculture, Development, and Urban Bias, *World Development*, Vol 36, No 8, pp 1342-1364.

Block A., Steven (1994), A New View of Agricultural Productivity in Sub-Saharan Africa, *American Journal of Agricultural Economics*, Vol. 76, No 3, pp 619-624.

------------------ (1995), The Recovery of Agricultural Productivity in Sub-Saharan Africa, *Food Policy,* Vol. 20, pp 385-405.

Bloom, David and Sachs, Jeffrey (1998), Geography, Demography, and Economic Growth in Africa, *Brookings Paper on Economic Activity,* available at http://www.cid.harvard.edu/archive/malaria/docs/brookafr.pdf

Bates, B.C., Z.W. Kundzewicz, S. Wu and J.P. Palutikof, Eds., (2008), Climate Change and Water, Technical Paper of the Intergovernmental Panel on Climate Change, IPCC Secretariat, Geneva, 210 pp.

Boko, M., I. Niang, A. Nyong, C. Vogel, A. Githeko, M. Medany, B. Osman-Elasha, R. Tabo and P. Yanda,(2007): "Africa. Climate Change 2007: Impacts, Adaptation and Vulnerability." *Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*, M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden and C.E. Hanson, Eds., Cambridge University Press, Cambridge UK, 433-467.

http://www.ipcc.ch/pdf/assessment-report/ar4/wg2/ar4-wg2-chapter9.pdf

Boubacar, Inoussa (2008): The Economic Impact of Drought on the Mean Yields and Yield Variability in Sahel, working paper, Department of Economics, University of Nebraska-Lincoln

Carswell, G. (2000), Agricultural Intensification in Ethiopia and Mali, IDS Report 48, Brighton, England, p.46

Cline, William R. (2007), Global Warming and Agriculture: Impact Estimates by Country, http://bookstore.petersoninstitute.org/book-store//4037.html

Coelli, T.J. (1996), A Guide to Frontier Version 4.1: A Computer Program for Stochastic Frontier Production and Cost Function Estimation, CEPA Working Paper # 7/96, Department of Econometrics, University of New England, Armidale, Australia

Coelli, Tim J. and Rao, Prasada D. S. (2005), Total Factor Productivity Growth in Agriculture: a Malmquist Index Analysis of 93 Countries, 1980–2000, *Agricultural Economics*, Vol. 32, pp 115-134

Collier, Paul and Gunning, J. (1999), Why Has Africa Grown Slowly?, *Journal of Economic Perspectives*, Vol. 13, No 2, pp. 3-22.

Deschenes, Olivier; Greenstone Michael (2007), The Economic Impacts of Climate Change: Evidence from Agricultural Output and Random Fluctuations in Weather, *American Economic Review*, Vol. 97, No.1, pp. 354-385

Dell, Melissa; Jones, Benjamin F. and Olken, Benjamin A. (2008), Climate Change and Economic Growth: Evidence from the Last Half Century, *Working Paper 14132*, NBER Working Paper Series, National Bureau of Economic Research

Easterly, William and Levine, Ross (1997), Africa's Growth Tragedy: Policies and Ethnic Divisions, *Quarterly Journal of Economics*, Vol. 112, No 4, pp. 1203-1250

Efron, Bradley (1979), "Bootstrap Methods: Another Look at the Jackknife, *Annals of Statistics*, Vol. 7, pp. 1-26

FAO (Food and Agricultural Organization of the United Nations), (2008), FAOSTAT Database, http://faostat.fao.org/

Frees, Edward W. (2004) *Longitudinal and Panel data: Analysis and Applications in the Social Sciences*; Cambridge University Press; Cambridge, UK

Fulginiti, Lilyan E.; Perrin, Richard K.; Bingxin, Yu (2004), Institutions and Agricultural Productivity in Sub-Saharan Africa, *Agricultural Economics*, Vol. 31, pp. 169-180

Fulginiti, Lilyan E.; Perrin, Richard K. (1997), LDC Agriculture: Nonparametric Malmquist Productivity Indexes, *Journal of development Economics*, Vol. 53, pp. 373-390

Galdeano-Gomez, Emilio (2008), Productivity Effects of Environmental Performance: Evidence From TFP Analysis on Marketing Cooperatives, *Applied Economics*, Vol. 40, pp. 1873–1888

Grier, Kevin B. and Tullock, Gordon (1989**),** An empirical analysis of cross-national economic growth, 1951–1980, *Journal of Monetary Economics*, Vol. 24, No 2, pp 259-276

Human Development Reports (various series) at http://hdr.undp.org/en/reports/global

IAC Report (InterAcademy Council) (2004), Realizing the Promise and Potential of African Agriculture, available online at: http://www.interacademycouncil.net/CMS/Reports/AfricanAgriculture/PDFs.aspx?returnID=6995

Intergovernmental Panel on Climate Change (2001), Impacts, Adaptation and Vulnerability, contribution of working group II to the third assessment report of IPCC

Jaeger, William K (1992), The Effects of Economic Policies on African Agriculture, World Bank Discussion Paper, WDP 147, Washington, D.C

Kabubo-Mariara, Jane and Karanja, Fredrick K. (2007), The Economic Impact of Climate Change on Kenyan Crop Agriculture: A Ricardian Approach, Policy Research Working Paper 4334, World Bank, Washington, D.C

Kurukulasuriya, Pradeep et al. (2006), Will African Agricultural Survive Climate Change?, *The World Bank Economic Review*, Vol. 20, No 3, pp. 367-388.

Le Nay, Jean and Mathis, Jean (1989), The impact of Drought on the National Accounts for Livestock in Sahelian Countries, *Review of Income and Wealth*, Vol.35, No.2, pp. 209-224

Little, Peter D; Stone, M. Priscilla; Mogues, Tewodaj; Castro, A. Peter and Negatu, Workneh (2006), Moving in Place: Drought and Poverty Dynamics in South Wollo, Ethiopia, *Journal of Development Studies*, Vol. 42, No. 2, pp. 200–225

Lobell, David B.; Cahill, Kimberly Nicholas, and Field, Christopher B. (2007), Historical Effects of Temperature and Precipitation on California Crop Yields, *Climatic Change*, Vol. 81, pp. 187–203

Lio, Monchi and Liu, Meng-Chun (2008), Governance and Agricultural Productivity: A Cross-national Analysis, *Food Policy*, Vol. 33, pp. 504-512.

Lusigi, Angela; Thirtle, Colin (1997),Total Factor Productivity and the Effects of R&D in African Agriculture, *Journal of International Development*, Vol. 9, No 4, pp. 529-538.

Maddison, David; Manley, Marita and Kurukulasuriya, Pradeep (2007), The Impact of Climate Change on African Agriculture: A Ricardian Approach, World Bank Working paper, WPS 4305, Washington, D.C

Mendelsohn, Robert; Dinar, Ariel and Dalfelt, Arne (2000), Climate Change Impacts on African Agriculture", available at:
http://www.ceepa.co.za/Climate_Change/pdf/(5-22-01)afrbckgrnd-impact.pdf

McKeown, A.W.; Warland, J. and McDonald, M.R. (2006), Long-term Climate and Weather Patterns in Relation to Crop Yield: a Minireview, *Canadian Journal of Botanic*, Vol. 84, pp. 1031-1036.

Nin, Alejandro and Yu, Bingxin (2008), Developing Countries and Total Factor Productivity Growth in Agriculture: New Evidence Using a Malmquist Index with Constrained Implicit Shadow Prices, Paper presented at the 11th Annual Conference on Global Economic Analysis, Helsinski, Finland, June 12-14. Available online at
https://www.gtap.agecon.purdue.edu/resources/download/3738.pdf

Peng, Shaobing; Huang, Jianliang; Sheehy, John; Laza, Rebecca; Visperas, Romeo; Zhong, Xuhua; Centeno, G., Khush, Grace and Cassman, Kenneth (2004), Rice yields decline with higher night temperature from global warming, Proceedings of the National Academy of Sciences of U.S.A., Vol. 101, pp 9971–9975.

Pinstrup-Andersen, Per; Lundberg, Mattias & Garrett, James L. (1995), Foreign Assistance to Agriculture: A win-win proposition. 2020 Vision Food Policy Report, Washington, DC: International Food Policy Research Institute.

Pratt, Alejandro Nin; Bingxin, Yu (2008), An Updated Look at the Recovery of Agricultural Productivity in Sub-Saharan Africa, IFPRI Research Paper 00787, Washington, D.C

Roncoli, Carla; Keith, Ingram and Kirshen, Paul (2001), The Costs and Risks of Coping With Drought: Livelihood impacts and Farmers' responses in Burkina Faso, *Climate Research*, Vol. 19, pp: 119-132

Sala-i-Martin, Xavier; Doppelhofer, Gernot; Miller, Ronald I. (2004), Determinants of Long Term Growth: A Bayesian Averaging of Classical Estimates Approach, *American Economic Review*, Vol. 94, No 4, pp. 813-35.

Sanders, John H.; Shapiro, Barry I. and Ramaswamy, Sunder: (1996), *The Economics of Agricultural Technology in Semiarid Sub-Saharan Africa*, Baltimore, MD: The Johns Hopkins University Press.

Simar, Leopold; Wilson Paul W. (1998), Sensitivity Analysis of Efficiency Scores: How to Bootstrap in Nonparametric Frontier Models, *Management science*, Vol. 44, No. 1, pp: 49-61

------------------- (1999), Estimating and Bootstrapping Malmquist Indices, *European Journal of Operational Research*, Vol. 115, pp. 459-471

Thirtle, Colin; Lin, Lin; Piesse, Jenifer (2002), The Impact of Research Led Agricultural Productivity Growth on Poverty Reduction in Africa, Asia and Latin America, The Management Center Research Paper 016, King's College, University of London, London, United Kingdom

World Development Indicator Online Database at www.worldbank.org/wbi/governance/data