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# Investigating the Impact of Climate Change on Agricultural Production in Eastern and Southern African Countries

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## Abstract

Climate change has been a significant issue since the end of the 20th century, and impacts a variety of economic sectors, primarily agriculture. The negative impacts of climate change on agricultural production are important because agriculture is closely linked to food security. Although they contribute the least to global pollution, it is estimated that African countries will be the most affected by climate variability. Our paper analyzes the impact of climate change on agricultural production in 11 Eastern and Southern African countries (ESA) during the period from 1961 to 2011 and estimates a panel data model for agricultural production using climate variables (e.g., annual precipitation and annual mean temperature) and economic factors (e.g., livelihood, fertilizer use, machinery, agricultural land, and labor) as explanatory variables. The results indicate that variable precipitation positively affects agricultural production, while the overall increase in annual mean temperature decreases agricultural production in ESA countries. Quantifying the impacts of climate change on agricultural production can help policymakers determine the best adaptation and mitigation measures.

**JEL Classification Numbers**: Q54; Q18

**Keywords:** Climate change; Agricultural production; Panel data model; Eastern and Southern Africa.

## Résumé

Le changement climatique est devenu une question d'actualité depuis la fin du 20ème siècle, et il a un impact sur les différents secteurs économiques, principalement l'agriculture. Les effets négatifs du changement climatique sur la production agricole sont importants parce que l'agriculture est étroitement liée à la sécurité alimentaire. Bien que leur contribution à la pollution globale soit moindre, il est prévu que les pays africains seront les plus affectés par la variabilité climatique. Notre papier étudie l'impact du changement climatique sur la production agricole dans 11 pays du Sud-est de l'Afrique pendant la période de 1961 à 2011. Nous estimons un modèle de données de panel pour la production agricole en utilisant des variables climatiques (la précipitation annuelle et la température moyenne annuelle) en plus des facteurs de production traditionnels comme variables explicatives. Les résultats trouvés montrent que la variable précipitation affecte positivement la production agricole, tandis que l'augmentation globale de la température moyenne annuelle fait diminuer la production agricole dans ce groupe des pays étudiés. La détermination de l'ampleur de l'impact du changement climatique sur la production agricole peut aider les décideurs à déterminer la meilleure stratégie d'adaptation et les mesures d'atténuation.

Codes JEL: Q54; Q18

**Mots-clés:** changement climatique; production agricole; modèle de données de panel; l'Afrique du Sud-est.

## 1. Introduction

Changes in precipitation and temperature, driven by a changing climate, have significantly affected global agriculture in recent years. Various reports from the Intergovernmental Panel on Climate Change (IPCC) and the United Nations Collaborative Programme on Reducing Emissions from Deforestation and Forest Degradation in Developing Countries (UN-REDD) have documented the overall effects of climate change; the IPCC's fourth assessment report indicates that most land areas will experience an increase in average temperature, along with more frequent heat waves, more stressed water resources, desertification, and periods of heavy precipitation. (IPCC 2007). These extreme weather events could adversely affect many countries in the world, especially those with an important share of GDP coming from agriculture. The regions that could be most adversely affected are Africa and South Asia; according to Dinar et al. (2008), climate change is expected to be detrimental to the major agricultural commodities yields in most tropical and sub-tropical regions. Precipitation is projected to decrease in the majority of African countries, with unequal distribution and repartition in time and space. These changes are anticipated to negatively impact the availability of agricultural land, the length of growing seasons, and the yields of major crops such as millet, sorghum, and maize.

Quantifying the economic effects of climate change's agricultural impacts has received increasing attention in the literature in recent years. Parry et al. (1999) estimate that a temperature increase of 2.5°C or more would cause a decline in crop yields and prompt food prices to soar as growth in global food demand outstrips any expansion in food production capacity. However, the effect of climatic change on global income is anticipated to be less significant, with small or negative changes in developing countries and positive changes in some developed countries (IPCC, 2001). In summary, climate variability will not only have an adverse impact on agricultural production, yields, and profitability but will also create additional hardships for poor, net-food-importing countries and thus widen global income inequality (Deschênes and Greenstone, 2004).

Climate change represents a big challenge to Africa's agriculture in particular because the capacity of African farmers to adapt to climatic change is limited. In Southern Africa (SA), precipitation declined by approximately 20% in the summers between 1950 and 1999. The vulnerability of poor populations in this region to climatic change and extreme weather events is worsened by the spread of HIV/AIDS, lack of access to land and water, low levels of technology and education, and institutional mismanagement (IPCC, 2001; Nhemachana et al., 2010). ESA's susceptibility to climate variability is shaped by the interaction between these different factors related to society, politics, economics, culture, and environment (Eriksen et al., 2008).

Climatic changes have already strongly affected agriculture in African countries by adversely impacting different farming systems (Gornall et al., 2010). Climate change may require adaptation and changes in farmers' practices to conserve and improve crop yields. Previous works studying the effects of climatic change on crop yields have generally used two methodologies: simulation models and statistical models. The caveat of these models is that they are based mainly on climate variables but do not consider economic variables such as prices and technology (Li et al., 2011). In reality, technological progress, which takes place regardless of climate change, also affects crop yields. Climate change is likely to induce further technological advance or adaptation that helps mitigate its effects.

Our study is based on the production function approach using aggregate data for analyzing the effects of climatic change on agricultural production in the ESA region. In this paper, we study the effects of climatic change on agricultural production using panel fixed-effects econometric models. More specifically, we estimate the effect of changes in mean annual temperature, annual precipitation, and a set of economic variables (agricultural land, labor, machinery, fertilizers, and livelihood) on agricultural production.

The majority of previous empirical studies using econometric or statistical models analyzed the impacts of climatic change on agricultural production or crop yields for individual countries; there are few studies on the sub-regions of Africa. These studies have found negative effects for any warming above current levels. Kurukulasuriya et al. (2006) studied the impact of climatic change on farmers' net revenues in 11 African countries, and found that increasing temperature adversely affects rain-fed farm revenues and livestock. Revenues from all farm types increase with precipitation.

Lotsch (2007) estimate that the African continent will lose, on average, 4.1% of its cropland by 2039 and 18% by 2099. According to the IPCC's fourth assessment report, the northern and eastern regions of Africa are expected to lose up to 15% of their current cropland area by 2039. In the case of southern Africa, initial gains will be offset by losses toward the end of the century. Only western Africa is projected to see an expansion in cropland area during the entire period.

Barrios et al. (2008) examine the impact of climatic change on the level of total agricultural production in Sub-Saharan Africa (SSA) and some other developing countries by estimating panel data econometric models. The results indicate that changes in climate variables, represented by rainfall and temperature, have negative effects on agricultural production in SSA. By contrast, climatic change does not affect other developing countries in the same manner.

Nhemachena et al. (2010) study the economic impacts of climate change on crop and livestock for a survey of different farmers in South Africa, Zambia, and Zimbabwe. Their results show that increasing temperatures and decreasing precipitation negatively affect net farm revenues in these countries. More recently, Ayinde et al. (2011) found that the effects of temperature and rainfall changes on agricultural productivity in Nigeria are both negative and positive.

In this study, we try to fill the literature gap by investigating the impact of climatic change on the agricultural production index by estimating panel data econometric models for the ESA sub-region. The use of the production function (PF) framework is dictated by the availability of data. The main advantage of using the PF framework is that it permits for control of economic variables (Deschenes and Greenstone, 2004), whereas the disadvantage is that it does not take farmers' responses to climate change into account. Farmers can take some precise adaptation measures by changing their production techniques, as well as the type of crops produced. This can bias the coefficients of climate variables when estimating the PF model (Barrios et al., 2008). However, because farmers in ESA countries rarely take such adaptation measures, the PF framework can be used to estimate the impact of climate change on agricultural production for the ESA countries in this study. We focus on 11 countries from ESA: Angola, Eritrea, Ethiopia, Kenya, Malawi, Mauritius, Mozambique, South Africa, Tanzania, Uganda, and Zambia. This region merits close attention because of both its economic and geographical diversity and its efforts to promote food security (as illustrated by Malawi's very successful Farm Inputs Subsidy Program).

The remainder of this article is organized as follows. In section 2, we analyze the impacts of climatic change on agriculture in ESA countries; section 3 presents the data and methodology used in this paper. Empirical results are presented in section 4; in the last section, we present policy implications and conclusions.

## 2. Impacts of Climatic Change on Agriculture

### *2.1 Overall Climatic Changes*

According to IPCC (2007), climate change is defined as follows: "climate change refers to a change in the state of the climate that can be identified by changes in the mean or variability of its properties and that persists for extended periods, typically decades or longer..." (p. 943). Greenhouse gases are primarily responsible for warming the planet, and the stock of greenhouse gases is expected to grow substantially from the burning of fossil fuels and from land use changes if action is not taken to reduce emissions. The growth in greenhouse gases will in turn lead to increasing temperatures and variability in rainfall trends. Hence, climate change can lead to temperature increases, changes and variability in precipitation, and a rise in sea levels, thereby increasing the intensity of such natural hazards as storms, floods, and droughts (IPCC, 2007).

Climate change is arguably the most important challenge facing the world in this century, and it is more serious in African countries, largely due to their geographic exposure (the geographical location of most African countries on the lower latitudes), low income, greater reliance on climate-sensitive sectors such as agriculture, and weak capacity to adapt to the changing climate. Africa saw an increase in average annual temperatures during the 20th century of approximately 0.5°C. Climate models estimate that throughout Africa, the median temperature increase by the end of this century will be between 3°C and 4°C (Eriksen et al., 2008). However, Africa contributes less than 5% of total carbon dioxide-equivalent emissions to global greenhouse emissions.

The climates of ESA vary, both intra- and inter-country. Estimates predict that changes in precipitation will lead SA to experience more drought, while Eastern Africa (EA) will experience more rainfall. Precipitation will decrease from June-August for SA and increase from December-February for EA. The risk of extreme weather events, such as flooding, is expected in EA (IPCC, 2007; Eriksen et al., 2008).[1]

During the last century, temperatures increased by 0.5°C, on average, across the globe, and are projected to increase by 1.5°C to 5.8°C by 2100 (Houghton et al., 2001). The warming trend observed in SA is consistent with the global trend throughout the 20th century. Temperatures have increased by over 0.5°C in this region (IPCC, 2001); Southern Africa experienced over 15 drought events between 1988 and 1992. This phenomenon has negatively affected the economies of Southern Africa through a reduction in agricultural production and exacerbated food insecurity. Ragab and Prudhomme (2002) estimate that by 2050, average annual temperatures will increase by 1.5 to 2.5° C in the south of SA and by 2.5 to 3.0° C in the north of SA, relative to the 1961-1990 average levels. High rainfall variability intra- and inter-years is predicted for the ESA region (Reason at al., 2005).

### *2.2 Impacts of Climatic Changes on Agriculture in ESA Countries*

It is well known that the agricultural sector is directly related to and affected by climatic factors (particularly precipitation and temperature). Thus, agriculture has been largely used to project the effects of climatic change and variability because precipitation and temperature directly enter agricultural production functions (Fisher et al., 2012).

Agriculture is the principal driver for the formation of GDP and is crucial for food security in the majority of African countries. Despite the economic importance of the sector in ESA countries, however, its performance is poor compared with other developing countries. Table 1 shows agriculture's share of GDP for all Africa, sub-Saharan Africa (SSA), and the ESA countries included in this analysis for different periods. In Africa as a whole, agriculture is a crucial part of the economy in most countries. However, some countries have become less dependent on agriculture in terms of GDP share; examples include South Africa and Mauritius, due to their fast economic growth. The agricultural sector contributes approximately 12% to Africa's total GDP, although the agricultural GDP share decreases over time for all of the African countries considered here in this study. The agricultural sector contributes more than 20% to the GDP of

[1] These projections are generated by highly sophisticated General Circulation Models.

ESA countries, except for Angola, Eritrea, South Africa, and Mauritius. In Ethiopia, the agricultural GDP share is approximately 46%, while in South Africa, it is only 2.5%. Table 2 shows that the annual growth of agricultural GDP share varies considerably from year to year, due mainly to climate variability. Multiple studies show that the increase in temperature and the decrease in precipitation have adversely affected agricultural production in Africa (Hulme, 1996; Parry et al., 2007; Eriksen et al., 2008; Chikozho, 2010).

*Table 1. GDP Share of Agriculture (%)*

| Years / Countries | 1965 | 1970 | 1980 | 1990 | 2000 | 2010 |
|---|---|---|---|---|---|---|
| Africa | 22.534 | 20.793 | 17.292 | 18.110 | 15.339 | 12.355 |
| Sub-Saharan Africa | 21.926 | 19.732 | 18.496 | 18.876 | 16.325 | 12.702 |
| Angola | - | - | - | 17.938 | 5.664 | 9.842 |
| Eritrea | - | - | - | - | 15.095 | 14.528 |
| Ethiopia | - | - | - | 54.341 | 49.877 | 46.729 |
| Kenya | 39.8 | 33.785 | 34.595 | 30.185 | 32.383 | 27.172 |
| Malawi | 49.936 | 43.971 | 43.733 | 45.0 | 39.539 | 30.148 |
| Mauritius | - | - | 13.132 | 12.850 | 6.965 | 3.653 |
| Mozambique | - | - | 37.085 | 37.118 | 24.009 | 29.759 |
| South Africa | 9.184 | 7.163 | 6.196 | 4.630 | 3.274 | 2.478 |
| Tanzania | - | - | - | 45.957 | 33.482 | 28.131 |
| Uganda | 52.276 | 53.777 | 72.029 | 56.576 | 29.384 | 24.248 |
| Zambia | 15.634 | 11.632 | 15.07 | 20.604 | 22.164 | 20.448 |

Source: WDI (2012)
(-): The data are lacking.

*Table 2. Annual growth of agriculture GDP (%)*

| Years / Countries | 1970 | 1980 | 1990 | 2000 | 2010 |
|---|---|---|---|---|---|
| Africa | 1.928 | 3.859 | -0.799 | 0.078 | 3.180 |
| Sub-Saharan Africa | - | 2.161 | -1.875 | 1.091 | 4.808 |
| Angola | - | - | -0.523 | 9.3 | 5.888 |
| Eritrea | - | - | - | -43.496 | 3.6 |
| Ethiopia | - | - | 5.878 | 3.052 | 5.130 |
| Kenya | -7.873 | 1.073 | 3.471 | -1.277 | 6.329 |
| Malawi | -1.324 | -6.543 | -0.244 | 5.298 | 1.966 |
| Mauritius | - | -34.186 | 9.602 | 33.829 | -1.348 |
| Mozambique | - | - | 1.100 | -11.792 | 5.930 |
| South Africa | -6.647 | 9.980 | -7.136 | 4.723 | 4.980 |
| Tanzania | - | - | - | 4.459 | 4.055 |
| Uganda | - | - | 5.238 | -0.438 | 0.325 |
| Zambia | 4.246 | -1.872 | -8.904 | 1.550 | 6.596 |

Source: WDI (2012).
(-): The data are lacking.

Agriculture remains the primary source of employment and income for most of the rural population of ESA. Table 3 shows that agriculture’s share of employment is approximately 60% in Africa and more than 60%

in the ESA countries considered in this analysis, with the exception of Mauritius (8.73%) and South Africa (8.69%). We do observe some other disparities among the study countries. In Angola, Ethiopia, Kenya, Mozambique, Tanzania, and Uganda, agriculture's share of employment exceeds 80%; however, as mentioned previously, it is below 10% in South Africa and Mauritius. Kenya has the highest share of employment in agriculture at 94%.

It is clear from Tables 1 and 3 that agriculture contributes significantly to the national income of many ESA countries by providing employment for a large proportion of the population and by creating GDP.

*Table 3. Employment share of agriculture (% of total employment)*

| **Years / Countries** | **1991** | **2000** | **2010** |
|---|---|---|---|
| Africa | 70 | 65.34 | 59.18 |
| Sub-Saharan Africa | 74.80 | 70.06 | 64.27 |
| Angola | 91.96 | 89.19 | 88.42 |
| Eritrea | - | 70.75 | 63.81 |
| Ethiopia | 90.49 | 90.08 | 82.02 |
| Kenya | 97.47 | 99.76 | 94.19 |
| Malawi | 92.06 | 87.72 | 79.18 |
| Mauritius | 18.56 | 13.24 | 8.73 |
| Mozambique | 92.30 | 86.85 | 83.63 |
| South Africa | 19.81 | 13.25 | 8.69 |
| Tanzania | 97.30 | 93.85 | 86.29 |
| Uganda | 90.79 | 86.3 | 85.67 |
| Zambia | 80.28 | 68.92 | 69.32 |

Source: WDI (2012).

African agriculture is mainly rain-fed, meaning that climate change (particularly variations in precipitation) can adversely affect crop yields and livestock, endangering farmers' incomes. Climatic change manifested through droughts has largely affected Ethiopia, Kenya, and Somalia (United Nations World Water Development Report, 2003). In addition to decreased precipitation and increased temperatures (Nicholson, 1994 and 2001), African agriculture is also coming under stress from population growth and urbanization. The annual urban population growth was approximately 4% in Africa from 1961-2011 (WDI, 2012). Table 4 shows population, urban population, and annual population growth in Africa and the ESA countries under investigation.

*Table 4. Population, urban population and annual population growth*

| Years / Countries | Population (million) | Urban population (% of total) | | Annual population growth (%) | |
|---|---|---|---|---|---|
| | | 1961 | 2011 | 1960-1961 | 2010-2011 |
| Africa | 1034.039 | 19.226 | 39.728 | 2.45 | 2.34 |
| Sub-Saharan Africa | 865.247 | 15.301 | 36.691 | 2.45 | 2.52 |
| Angola | 19.618 | 10.848 | 59.142 | 1.81 | 2.77 |
| Eritrea | 5.415 | 10.077 | 21.363 | 2.52 | 3.03 |
| Ethiopia | 84.734 | 6.663 | 17.018 | 2.32 | 2.13 |
| Kenya | 41.609 | 7.610 | 23.984 | 3.11 | 2.67 |
| Malawi | 15.380 | 4.493 | 15.695 | 2.31 | 3.17 |
| Mauritius | 1.286 | 33.941 | 41.797 | 3.19 | 0.39 |
| Mozambique | 23.929 | 3.855 | 31.215 | 1.98 | 2.27 |
| South Africa | 50.586 | 46.744 | 61.986 | 3.13 | 1.18 |
| Tanzania | 46.218 | 5.402 | 26.742 | 2.92 | 3.02 |
| Uganda | 34.509 | 4.635 | 15.579 | 3.17 | 3.19 |
| Zambia | 13.474 | 19.190 | 39.165 | 2.91 | 2.15 |

Source: WDI (2012).

Water resources are also essential for the growth of agricultural commodities. A decrease in rainfall, and an increase in precipitation variability and irregularity, have negatively affected these commodities' harvested areas, and hence agriculture as a whole, in Africa. Table 5 shows the average harvested area of the leading agricultural commodities in ESA countries from 1961-2011. The ESA region as a whole has more than 50% of its agricultural land allocated to cereals, with maize as the main staple crop (Table 5). South Africa is the largest maize producer in the region, mainly due to the contribution of irrigated farmlands, followed by Tanzania. Mauritius and Eritrea have the smallest areas of maize. Sorghum and millet are also important crops, especially in the drier areas. Ethiopia is the highest producer of sorghum in the region, while Uganda is the highest producer of millet. Some African countries cannot meet their national demand for maize and sorghum through domestic production, so they import their additional needs, mainly from South Africa. Wheat is produced mainly under irrigation in South Africa and Ethiopia. South Africa has the highest yield per hectare of wheat in the region, averaging more than four tons (WDI, 2012). To meet the demands of Africa's growing populations, agricultural productivity will need to increase, which will impact the availability of water, even taking irrigation into account.

*Table 5. Average harvest area of leading agricultural commodities in ESA countries, 1961–2011 (thousand hectares)*

| *Countries* | *Barley* | *Maize* | *Millet* | *Rice* | *Sorghum* | *Wheat* |
|---|---|---|---|---|---|---|
| Africa | 4684.570 | 22222.187 | 15557.957 | 5859.481 | 18466.517 | 8678.446 |
| Angola | 0 | 740.305 | 139.651 | 13.341 | 0 | 8.373 |
| Eritrea | 44.888 | 20.483 | 70.243 | 0 | 273.944 | 25.301 |
| Ethiopia | 928.055 | 1159.190 | 273.575 | 12.842 | 1043.855 | 925.088 |
| Kenya | 20.894 | 1413.731 | 85.668 | 10.918 | 160.116 | 129.351 |
| Malawi | 0 | 1218.055 | 27.369 | 33.994 | 67.112 | 1.256 |
| Mauritius | 0 | 0.332 | 0 | 0.045 | 0 | 0 |
| Mozambique | 0 | 888.368 | 38.481 | 107.554 | 335.995 | 4.887 |
| South Africa | 84.413 | 4079.033 | 19.996 | 1.242 | 238.569 | 1402.060 |
| Tanzania | 3.183 | 1634.667 | 266.008 | 361.868 | 532.374 | 51.229 |
| Uganda | 0 | 475.309 | 449.392 | 40.512 | 273.259 | 5.859 |
| Zambia | 2.047 | 731.636 | 79.066 | 9.402 | 48.250 | 8.156 |

Source: FAOSTAT (FAO, 2012)

Rosenzweig and Parry (1994) show that climate change will negatively affect agricultural productivity in most developing countries. Climate variability and change are expected to compromise agricultural production and food security severely in ESA countries. Hamilton et al. (2001) predict that climate change and variability will reduce crop yield by 10-20% in Mozambique, Tanzania, Uganda, Botswana, and Namibia. These results are not different from those obtained by Parry et al. (2004), who find that changes in cereal yields will range from -10% to +3%, whereas maize yields will decrease by 30% in Africa as a whole. According to IPCC (2007), Africa is the most vulnerable continent to climatic change. Frequent and prolonged droughts, mainly in SA countries, have negatively affected the productivity of the region’s main crops and hence affected food security. It is projected that Botswana, Zimbabwe, and Ethiopia will be more vulnerable to climatic changes than Tanzania or Zambia (Eriksen et al., 2008). It is also estimated that the cereal production will decrease by 12% in SSA (Fischer et al., 2005; Shah et al., 2008).

Agriculture and farming practices are strongly affected by the long-term mean climate state. Global warming can significantly impact agricultural productivity, farm incomes, and food security. In some regions, the impact of warming on agriculture is positive, while in others, it is negative. For example, in the mid- and high latitudes, crop yields, such as cereals and cool season seed crops, are expected to increase (Olesen et al., 2007). In the Russian Federation, the increase in temperature may increase the yield of some crops by 64% by the 2080s (Fisher et al., 2005). By taking the effect of technology into account, Fisher et al. (2005) found that rising temperatures in Russia could increase wheat yields by between 37-101% by the 2050s. Additionally, the yields of maize, sunflower, and soybeans are expected to increase by 30% by the

2050s in southern Europe (Olesen et al., 2007). However, in regions where temperatures are already high, such as Africa, global warming will increase heat stress and water evaporation and thus will be more detrimental to agricultural production. A 2°C increase could cause an increase in wheat production by approximately 10% in the mid-latitudes and a decrease of 10% at low latitudes (Gornall et al., 2010). Lobell and Field (2007) study the relationships between temperature, rainfall, and yields for some crops such as wheat, maize, and barley. They found that warming since 1981 has caused an annual loss of US$5 billion.

Evidence from Ringler et al. (2010) reveals that climate change will affect crop area, yield, and production in SSA. Negative yield effects are projected to be the largest for wheat, followed by sweet potato; overall yields for millet and sorghum are projected to be slightly higher under climate change. The authors found that EA zones show projected yield increases for four (rice, sweet potato and yam, cassava, sugar cane) out of five main crops (maize, rice, sweet potato and yam, cassava, sugar cane). SA zones have projected declines for maize, rice, and cassava.

The anticipated increase in the frequency and magnitude of extreme climate events, such as floods and droughts, will have far-reaching impacts on ESA's agriculture and food security. In this region, the effects of extreme climate events will be aggravated by weak infrastructure, poor natural resource management, high poverty levels, and dependence on rain-fed agriculture. Additionally, farmers in ESA countries are mainly smallholders. They practice low-level farming activities and are easily impacted by extreme climate and weather (Eriksen et al., 2008).Climate variability will reduce the production of maize, sorghum, millet, sugar cane, and wheat by approximately 10%. However, the impacts of climatic change are not the same within and between the ESA countries.

Schlenker and Lobell (2010) show that maize production will fall by 22% in 2050 in SSA as a result of climatic change. The study also shows that the impact of climate change will be more severe for well-fertilized crops of modern seed varieties. The 1992 drought was estimated to have caused a 0.4-1% loss in economic growth in South Africa. The same drought reduced Zambian agriculture output by 39% and GDP by 2.8%. During this period, GDP per capita declined by 25% in Zambia, leading a growing number of people into poverty.

## 3. Methodology and Data

### *3.1 Conceptual Model*

The present study uses a production function approach to investigate the effects of climate factors on the agricultural production index. We are restricted to this approach because data are only available on an aggregate basis for the inputs in ESA countries. Additionally, consistent time series of temperature and precipitation are not available for the relevant commodities produced in ESA countries (rice, maize, millet, or wheat). The available data do not allow the use of other competing models. In an attempt to identify the impacts of climate variables, the analysis controls for agricultural inputs, such as agricultural land, livestock, labor, machinery, and fertilizers.

We consider a production function in which the agricultural production index is a function of some economic inputs and climate factors: Y=f (L, V, M, F, A, R, T). Y represents the agricultural production index; L, V, M, F, and A are labor, livestock, machinery, fertilizer, and agricultural land, respectively. Machinery, representing the number of tractors, is the proxy of the capital stock. Climatic factors that may affect agricultural production are represented by precipitation, R, and temperature, T. The agricultural production model in this analysis has the following specification form:

$$Y_{it} = \beta_0 * V_{it}^{\beta_1} * A_{it}^{\beta_2} * L_{it}^{\beta_3} * M_{it}^{\beta_4} * F_{it}^{\beta_5} * e^{\varepsilon_{it}} * e^{\beta_6 R_{it} + \beta_7 R_{it}^2 + \beta_8 T_{it} + \beta_9 T_{it}^2} \quad (1)$$

The production function specified in equation (1) is similar to those of Barrios et al. (2008) and Lee et al. (2012). As explained by the FAO, to permit intercomparisons, the unit of production used is "international dollars" rather than production quantity or local currency. V represents the livestock production index (2004-2006 = 100); A is the agricultural land expressed in hectares; L represents the total number of the population that is economically active in agriculture; M represents the number of agricultural tractors; and F represents the total agricultural consumption of fertilizers in 1000 tons. Climate variables are precipitation and temperature. R represents average precipitation in depth (mm per year), and T represents mean annual temperature (°C per year).

### *3.2 Data Sources*

For this analysis, cross-sectional time series data are used. The empirical analysis is based on the cross-section data from 11 ESA countries for the time period between 1961 and 2011. Some observations are missing due to data being unavailable for a few countries; therefore, the panel data in the model are unbalanced. The following countries are included in the model: Angola, Eritrea, Ethiopia, Kenya, Malawi, Mauritius, Mozambique, South Africa, Tanzania, Uganda, and Zambia. Table 6 shows the definition of the variables used in the model and their sources. Temperature and precipitation data were obtained from NOAA Satellite and Information Service, National Environmental Satellite, Data, and Information Services (NESDIS). We used country-level climate data for mean annual temperature (°C) and total yearly precipitation (mm), which are the most common climatic variables considered in these types of studies. For economic variables, such as the agricultural production index, livestock production index, economically active population in agriculture, agricultural land, agricultural machinery, and fertilizer consumption, the data in the model were obtained from the Food and Agriculture Organization of United Nation Statistics Division (FAOSTAT). Table 7 shows the descriptive statistics of the various variables used in the model.

*Table 6. Variable Definitions and Sources*

| Variable (Indicator Name) | Series Code | Short definition | Source |
|---|---|---|---|
| Agriculture production index (2004-2006 = 100) | Y1 | It indicates the evolution of the aggregate volume of agricultural production for each year from the base period 2004-2006. | FAOSTAT (2012) and WDI (2012) |
| Livestock production index (2004-2006 = 100) | V | It indicates the evolution of Livestock production for each year from the base period 2004-2006. | FAOSTAT (2012) and WDI (2012) |
| Agricultural land (hectares) | A | It is the share of arable land area which is cultivated. | FAOSTAT (2012) and WDI (2012) |
| Economically active population in agriculture | L | It reflects the number of people working in agriculture. | WDI (2012) |
| Total Fertilizers Consumption (tonnes) | F | Total consumption of fertilizers in agriculture in 1000 tons | FAOSTAT (2012) |
| Agricultural machinery, tractors | M | It is the number of wheel and crawler tractors (excluding garden tractors) used in agricultural production. | FAOSTAT (2012) |
| Average annual precipitation (mm per year) | R | It is the long-term average of annual precipitation in a country. | NESDIS |
| Mean annual temperature (°C per year) | T | It is the mean annual temperature in a country**.** | NOAA Satellite and NESDIS |

*Table 7. Descriptive Statistics*

| Variable | Obs | Mean | Std. Dev. | Min | Max |
|---|---|---|---|---|---|
| Y1 | 497 | 69.984 | 27.783 | 22.21 | 189.25 |
| V | 497 | 65.617 | 29.419 | 18.41 | 180.48 |
| A | 529 | 3.36e+07 | 2.79e+07 | 89000 | 1.01e+08 |
| L | 339 | 6618171 | 6478934 | 47000 | 3.24e+07 |
| F | 510 | 106466.6 | 219315.9 | 0 | 1232886 |
| M | 441 | 18273.49 | 41622.35 | 198 | 175557 |
| R | 506 | 970.088 | 371.237 | 238.56 | 2731.08 |
| T | 506 | 21.851 | 2.179 | 16.88 | 27.37 |

### *3.3 Econometric Model*

Because we consider different countries across many years, the analysis will include a mechanism to represent regional and temporal scale variations. Econometrically, these time and spatial effects can be tested by running the model as a two-way fixed-effects model. After taking log on both sides of the model given by equation (1), for any country i at time t, the panel data model is given by equation (2):

$$\ln Y_{it} = \beta_0 + \beta_1 \ln V_{it} + \beta_2 \ln A_{it} + \beta_3 \ln L_{it} + \beta_4 \ln M_{it} + \beta_5 \ln F_{it} + \beta_6 R_{it} + \beta_7 R_{it}^2 + \beta_8 T_{it} + \beta_9 T_{it}^2 + \mu_t + \alpha_i + \varepsilon_{it} \quad (2)$$

where lnY, lnV, lnA, lnL, lnM, and lnF represent the logarithms of agricultural production, livestock, agricultural land, labor, machinery, and fertilizer consumption, respectively. For climate variables, their squared terms are also integrated in the model to take into account the non-linear relationship between agricultural production and climate factors. There are two reasons to include the *fixed* effects (FE). First, the country-specific effects ($\alpha_i$) absorb any unobserved time-invariant effects. Additionally the time-varying effects ($\mu_t$), which are proxied by time dummies, represent technology progress. Each year is associated with a dummy variable. Finally, the error term is given by $\varepsilon_{it}$. The $\beta_s$, for s = 1, 2, …, 9, are the coefficients to be estimated. Because all of the input variables in the model are expressed in natural logarithms, their coefficients are interpreted as elasticities of agricultural production with respect to each input.

After estimating the impact of climate variables on agricultural production using the above model for the period of 1961-2011, we shall evaluate the impact of future changes in climate conditions on agricultural production. We will employ climate change scenarios to create new adjusted variables for temperature and precipitation. The current variables in the primary data set will be added by some °C to calculate the new temperature variable; likewise, the precipitation variable will be multiplied by a factor to generate future precipitation scenarios. Projected changes in agricultural production will be derived using these forecasts. Overall, it is expected that precipitation will decline and temperatures will rise in the ESA region, both of which will negatively affect agricultural production (Sharka et al., 2013).

## 4. Empirical and Simulation Results

### *4.1 Empirical Results*

We consider four versions of the model given by equation 2. In the first version of the model, we introduce precipitation and temperature as climate variables. In the second version, we introduce precipitation, its squared term, and temperature as climate variables. In the third version, the squared term of precipitation is replaced by the squared term of temperature. In the fourth version, we consider precipitation, temperature, and both their squared terms. The Hausman test rejects the null hypothesis that a random effect model is appropriate for the four versions; the results of this test are given in Table 8. The test suggests the use of an FE model for the four versions. The results of the Wooldridge test and a Breush Pagan test indicate the existence of autocorrelation of errors of order one and the presence of heteroscedasticity in the term errors.

Using the robust standard errors in the four versions of the fixed effect model to correct for the presence of heteroscedasticity and autocorrelation of the errors, the results do not change significantly.

In all of the models estimated, precipitation is expected to positively impact agricultural production because agriculture in most countries relies heavily on rainfall due to insufficient irrigation; temperature has a negative effect. As mentioned earlier, the model includes a quadratic term of each of the climate variables to capture the non-linear relationship with agricultural production. The sign of a linear term and a quadratic term is always opposite each other because of the quadratic formation of climate variables. However, the coefficients of the squared terms of precipitation and temperature are insignificant in the three versions 2, 3, and 4. Table 8 presents only the regression results of fixed effect panel analysis for the model given by equation 2 without squared terms.

As shown in Table 8, the coefficient of precipitation is positive and significant at 5%. The coefficient of temperature is negative but insignificant.

To avoid complicating the analysis and our interpretation of climate variables with quadratic terms, the marginal impacts and elasticities of climate variables are calculated. The impacts of climate variables are analyzed later with the results of marginal impacts and elasticities. The coefficients of all production input variables indicate the elasticities because both production and input variables are log-forms. As expected, most input variables are significant in the model. Agricultural land has a positive impact on agricultural production, with a significant coefficient at 1%. It has a bigger effect on agricultural production than any other input variable in the model. If agricultural land is increased by 10%, agricultural production will be increased by 11.17%, holding other variables constant. The coefficient of the livestock index is positive and significant at 1%. Labor has a positive sign and is significant at 1%, which confirms that agriculture is labor-intensive in ESA countries. Accordingly, when labor is increased by 10%, agricultural production increases by 3.14%, holding other variables constant. Fertilizer has a positive effect on production but is insignificant. The results show that the elasticity of agricultural machinery is negative, but not significant. This result is surprising and can perhaps be attributed to the fact that data on machinery use are not reliable.

*Table 8. Empirical Results*

| Variables \ Models | Model 1 |
|---|---|
| V | 0.370<br>(0.00) |
| A | 1.117<br>(0.00) |
| L | 0.314<br>(0.00) |
| F | 0.013<br>(0.20) |
| M | -0.040<br>(0.35) |
| R | 0.00009<br>(0.02) |
| T | -0.026<br>(0.27) |
| Constant | -19.78<br>(0.00) |
| Observations | 234 |
| F-test | 67.25<br>(0.00) |
| F-u | 55.40<br>(0.00) |
| R-sq | 0.918 |
| chi2 of Hausman test | 119.25<br>(0.00) |
| Wooldridge test Stat for autocorrelation | 32.561<br>(0.00) |
| Breush Pagan test Stat for heteroscedasticity | 43.781<br>(0.00) |

Notes: (1) p-values are between parentheses; (2) Time dummies are included.

## *4.2 Marginal Impact Analysis*

The expected marginal impacts of precipitation and temperature on agricultural production evaluated at the mean are calculated respectively by derivation of equation (1) to precipitation and temperature:

$$E(\frac{dY}{dR}) = (\beta_6 + 2\beta_7 E(R)) * E(Y) \qquad (4)$$

$$E(\frac{dY}{dT}) = (\beta_8 + 2\beta_9 E(T)) * E(Y) \qquad (5)$$

where $\beta_6$ and $\beta_8$ are linear term coefficients for precipitation and temperature and $\beta_7$ and $\beta_9$ are quadratic term coefficients for precipitation and temperature variables. E(R), E(T), and E(Y) are mean values of precipitation, temperature, and agricultural production variables, respectively.

The elasticities of precipitation and temperature are derived from equations (4) and (5), respectively, by multiplying the two sides of equation (4) by $\frac{R}{Y}$ and equation (5) by $\frac{T}{Y}$. They are given by the following formulas:

$$E(\frac{dY/Y}{dR/R}) = (\beta_6 + 2\beta_7 E(R)) * E(R) \qquad (6)$$

$$E(\frac{dY/Y}{dT/T}) = (\beta_8 + 2\beta_9 E(T)) * E(T) \qquad (7)$$

Table 9 shows the marginal impacts and elasticities of rainfall and temperature on agricultural production. They are calculated using mean values of climate variables and the regression coefficients from the first version of the model given by equation 2. Increases in precipitation marginally increase agricultural production, while increases in temperature marginally decrease agricultural production in ESA countries. For example, if annual precipitation decreases by 10%, agricultural production will decline by approximately 0.97%, whereas if mean annual temperature rises by 10%, agricultural production will fall by approximately 5.8%. The effect of warming is more severe in ESA countries.

*Table 9. Estimates of marginal impacts and elasticities of climate variables*

| | **Marginal impacts** | **Elasticities** |
|---|---|---|
| Precipitation | 0.0069 | 0.0965 |
| Temperature | -1.885 | -0.5886 |

Previous studies have predicted that the future climate of eastern and southern Africa will be hotter and drier. We suppose that by 2050, average annual temperatures will increase by between 1.5 (optimistic scenario) and 2.5° C (pessimistic scenario), while precipitation will decrease by between 10% (optimistic scenario) and 20% (pessimistic scenario) compared with the 1961-2011 average. Because the mean annual temperature of the period of this study is 21.851°C, and the mean agricultural production index is 69.984, an increase in temperature of 1.5°C will decrease the agricultural production index by 4.04%, while an increase of 2.5°C will decrease the agricultural production index by 6.73%, holding all other factors constant. A decrease in precipitation of 10% will decrease the agricultural production index by 0.965%, while a 20% decrease in precipitation will decrease the agricultural production index by 1.93%, holding all other factors constant. The results of these simulations are based on elasticities and are given in Table 10.

*Table 10. Simulation results*

| | Temperature increase effects on agricultural production index (in %) | Precipitation decrease effects on agricultural production index (in %) |
|---|---|---|
| Optimistic scenario | -4.04 | -0.965 |
| Pessimistic scenario | -6.73 | -1.93 |

## 5. Conclusions

This paper analyzes the impact of climate change on agricultural production using fixed effect country-level panel analysis in selective ESA countries from 1961 to 2011. The results show that the rise in mean annual temperatures and the decrease of annual precipitation will negatively affect agricultural production in ESA countries. If temperatures increase by 1.5°C (respectively, 2.5°C), agricultural production will decline by 4.04% (respectively, 6.73%), holding all other factors constant. If annual precipitation decreases by 10% (respectively, 20%), agricultural production will decrease by 0.965% (respectively, 1.93%), holding all other factors constant.

As many studies indicate, African agriculture is very vulnerable to climate change. Because most of the investigated countries are poor and heavily rely on agriculture, climate change will continue to be a major concern. The characteristics of ESA countries and their farmers' practices make this region's agriculture even more sensitive to climatic change. As climate change negatively affects the region's agricultural production, ESA's crop yields will decline. Consequently, the prices of major agricultural products, such as maize, rice, millet, and wheat, will increase and may increase the rate of malnutrition, particularly among poor populations. Adaptation measures, such as developing new crop varieties that are more tolerant to higher temperatures, increasing investment in agricultural productivity, and developing proper adaptation programs or policies, will be necessary to effectively respond to climate change. In the past, policymakers have suggested that international agricultural trade could be one such adaptation measure (Li et al., 2011). However, the increases in food prices in 2008 and 2010 have sparked a debate about food security. In this study, we attempt to contribute to that debate by setting out the challenges that face agricultural production, and hence food availability, in the ESA region.

Another important policy improvement would be the development and introduction of new crop varieties, which could be supported by encouraging R&D efforts. Technological progress can reduce the adverse effects of climatic variability, and could have implications for global adaptation efforts favoring African countries, which contribute the least to climate change and yet remain its biggest victim (Li et al., 2011).

In short, a variety of different adaptation measures should be taken to achieve sustainable development goals in ESA countries.

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