Impact of Climate Change on Agricultural Productivity Growth in Southern African Customs Union (SACU)

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Abstract- The specific objective of this study is to determine the potential impact of rainfall, and temperature anomalies on Total Factor Productivity (TFP) growth of agriculture in SACU member nations, namely, Eswatini, Lesotho, Namibia, Botswana and South Africa. The analysis was conducted in two phases using time series data between 1981 and 2018. In phase one, agricultural TFP growth in the region was estimated and decomposed with Data Envelopment Analysis (DEA) Mamquist productivity measure. In the second phase, a panel regression model was used to investigate the relationship between the estimated TFP growth and the climate variables. The results show that all the countries within SACU made technological progress in their agricultural productivity growth apart from Eswatini. The effect of climate change on the regional agricultural productivity growth is negative and significant and there seems to be an urgent need for all the stakeholders in SACU agricultural sector to take proactive steps on climate change adaptation options.

Index Terms- Agriculture, Climate Change, SACU, Total Factor Productivity

I. Introduction

Agricultural productivity growth explains resource-use efficiency in the agricultural sector. It measures the economic performance of the agricultural sector and factors influencing farm incomes. The main focus of this research is on agricultural productivity growth in the South African Community Union (SACU) member nations, namely, Botswana, Eswatini, Lesotho, Namibia and South Africa. Although, the agricultural sector in SACU is not a major contributor to the region's Gross Domestic Product (Table 1), it is essential to study because of (i) the large percentage of the population employed in the agricultural sector in the region, (ii) the levels of poverty and (iii) unemployment in the region (Table 2).

Table 1: Agriculture Contribution to GDP in SACU Countries

Country	2015	2016	2017	2018	2019	average
Botswana	2.20	2.05	1.99	1.88	1.79	1.98
Eswatini	9.59	8.95	8.36	7.80	7.29	8.40
Lesotho	4.97	5.87	6.12	6.93	7.69	6.32
Namibia	5.90	6.16	7.00	7.52	8.19	6.95
SA	2.08	2.18	2.29	2.40	2.52	2.29
Average	4.95	5.04	5.15	5.31	5.50	5.19

Source: World Bank Development Indicator, SA is South Africa

The proportion of the population employed in the agricultural sector in the region are about 26% in Botswana, 69% in Eswatini, 57% in Lesotho, 20% in Namibia, and 6% in South Africa. Their levels of poverty are 19%, 63%, 60%, 27% and 56% respectively. The unemployment rate is high in all the countries – 20% in Botswana, 28% in Eswatini, 27% in Lesotho, 30% in Namibia and 27% in South Africa. A major route to stem the rising poverty and unemployment in the countries is to improve their agricultural productivity growth but climate change might be a serious limiting factor.

Table 2: Average Agricultural Labour Force, Poverty And Unemployment Rates In SACU Countries: 2015-2019

Country	Poverty	Unemployment	Labour Force
Botswana	19.40	20.00	26.00
Eswatini	63.00	28.10	68.98
Lesotho	59.60	27.25	57.00
Namibia	26.90	29.60	20.12
SA	55.50	27.10	5.53

Source: World Bank Development Indicator, SA is South Africa

An essential aspect of SACU agreement of 2002 is Article 39 on the agricultural Policy for the member countries. The article states that (i) member states recognize the importance of the agricultural sector to their economies; and (ii) member states agree to cooperate on agricultural policies in order to ensure the coordinated development of the agricultural sector within the Common Customs Area. In terms of trade relations, Article 31 is directly linked with article 39. Article 31 states that member states shall establish a common negotiating mechanism for the purpose of undertaking negotiations with third parties. Despite the laudable agricultural policy for the union, climate change has become a growing concern within the Southern African Customs Union (SACU). Severe drought and floods have also become a constant threat to livelihood in the countries, leading to water shortages and land degradation, as well as increased vulnerability to other natural disaster (IIED, 2011).

Though, there exists substantial empirical evidence on impact of climate change on agricultural productivity globally, regionally and at country levels (Mendelsohn, 1994; Hossain 2008; Knox et al., 2012; Tayebi, 2016; and Liang, 2017), there is limited empirical analysis on the negative effects of climate change on the African agricultural economy both collectively and at regional and individual country levels. Because of dearth of the literature on this issue in the continent, there is yet to be a consensus on the magnitude of its impact on agricultural productivity growth both at the regional and country specific levels. Therefore, this article aims at quantifying the implications of climate change on agricultural productivity in SACU member nations. Specifically, the article attempts to answer the following research questions: What is the level of agricultural productivity growth in SACU member countries and to what extent do temperature and rainfall affect agricultural productivity growth in SACU?, and is there any significant difference in the impact of climate change on the agricultural productivity growth of SACU countries?

This article is organized into five sections. Following this introduction is Section II that contains some literature review on climate change and agricultural productivity growth. Section III presents the model and how the parameters of interest are estimated while Section IV shows the results and discussion of key findings. Section 5 concludes the article.

II. Literature REVIEW

There are large bodies of empirical literatures on the determinants of agricultural productivity growth and climatic variables have become more important recently due to global warming and associated greenhouse effects. Some of the previous studies are reviewed in this section, many of the studies are however, conducted in developed economies. In Australia, weather proxied by de-trended rainfall data posed significant risk to the growth of Total Factor Productivity (TFP) in agriculture (Mullen & Cox, 1995). It has been argued that sensitivity of agriculture to climatic events depends on the stage of economic development (Mendelsohn, Dinar, & Sanghi, 2001). If the development of improved technologies encouraged capital to be substituted for climate, sensitivity of agriculture to climate would be higher in developing countries than that of developed countries. In order to test this hypothesis, they examined a climate response function for India, Brazil, and the USA. They showed that increasing development reduces sensitivity of agriculture to climate.

In Norway, temperature and precipitation positively affect yields of potatoes, barley, oats, and wheat over the period 1958–2001 in 18 per cent of the cases. In 20 per cent of the cases, the effect of increased precipitation is negative on the crop yields (Torvanger, Twena, & Romstad, 2014). The results were sensitive to the geographical area in Norway and the types of crops. For instance, the climate change effects became stronger as one move from South to North. In terms of crops, potatoes had the strongest effect. Likewise, damaging effect of precipitation was more evident in the western part of Norway, and in terms of crops, the negative effect was more pronounced for barley.

In Iran, Pakistan, Turkey and Syria in the Middle East, a translog production function was used in estimating TFP growth in agriculture over the period 1980-2010 (Tayebi & Fulginiti, 2016). Precipitation, temperature, drought and irrigation were included in the analysis. The results indicated increasing agricultural productivity during the period with innovations contributing approximately 30% to agricultural output growth. Temperature and precipitation played a significant role in agricultural production and most frequent extreme drought episodes and irrigation affect agricultural productivity growth in the region substantially.

Few of the empirical literatures exist on African Agriculture (Ajetomobi, 2016; Knox et al., 2012; Schlenker & Lobell, 2010) Schlenker & Lobell, (2010) combined historical crop production data and weather data in a panel analysis to show that a robust model of yield response to climate change emerges for several key African crops. By mid-century, the mean estimates of aggregate production changes in SSA in their preferred model specification were 22%, 17%, 17%, 18%, and 18% for maize, sorghum, millet, groundnut, and cassava, respectively. Knox et al., (2012) assessed the projected impacts of climate change on the yield of eight major crops in Africa and South Asia using a systematic review and meta-analysis of data in 52 original publications from an initial screen of 1144 studies. They found that climate change impact on crop yields in Africa and South Asia is robust for wheat, maize, sorghum and millet, and either inconclusive, absent or contradictory for rice, cassava and sugarcane. Ajetomobi (2016) examined how extreme weather conditions affected the mean and variance of the yields of 18 food crops in Nigeria over a period of 42 years (1971-2012) using Just and Pope stochastic production function (Just & Pope, 1979). He showed that the productivity of more than half of the staple crops in Nigeria was threatened by increase in total annual rainfall and extreme temperature nationally and across states in Nigeria.

Unlike developed world studies, the evidence on the relationship between climate change and agricultural productivity in Africa examined the impacts of climate variables on partial productivity measures such as crop yields and economic returns. These measures cannot account for the impacts at the national-level. Estimating the relationships between climate change and TFP is important to understanding whether current agricultural productivity growth will continue into the future. In this study therefore, we estimate agricultural productivity growth for SACU and analyzed the relationship between climate variations and agricultural TFP changes.

III. MATERIALS AND METHODS

Following previous studies (Huffman & Evenson, 2006; Zhong, Hu, & Jiang, 2019) we assumed that farmers' production per unit input can be represented by the Total Factor productivity (TFP) in Agriculture. Mathematically,

$$TFP = \frac{y}{f(x)} \qquad (1)$$

Where y is the index of aggregate output and $f(x)$ is the index of farm inputs such as land, labour, and capital (especially for agricultural research and development). In this study therefore, we assumed a production function for a SACU member state with disembodied technological change, where y is a member state total agricultural output measured as an output index. The production function is as follows

$$y = TFPf(l, k, m) \qquad (2)$$

The TFP is usually hypothesized to be a function of the government's investment in agricultural research and development and related factors. l is the labour, k is the physical capital and m, is the material input. From (2)

$$TFP = \frac{y}{f(l,k,m)} = \alpha(R\&D) \qquad (3)$$

Where $R\&D$ denotes research and development investment by the member state. Taking the log of both sides of (3), and adding the error term, the baseline econometric equation is as follows:

$$\ln(TFP) = \alpha + \ln(R\&D) + \varepsilon \quad (4)$$

Where ln is the natural logarithm and ε is the error term. The main objective of this study is to examine the impacts of climate change on TFP, therefore, following the model used by Huffman et al. (2006)], we modified (4) by adding two climate variables, namely, temperature anomaly (T) and rainfall anomaly (P). The modified model is described as follows:

$$\ln(TFP)_{it} = \alpha + \beta_1 \ln(R\&D)_{it} + \beta_2 \ln(T)_{it} + \beta_3 (P)_{it} + \varepsilon \quad (5)$$

Where it represent SACU member states, and year respectively. $R\&D$ is defined as the government's public budget investment in agricultural research and development. The essence is to enhance technical innovation in agriculture so as to boost productivity of the sector (Alston et. al., 2009). It is defined as the agricultural research spending as a share of value added in agriculture and obtained from FAO statistical database. The actual agricultural sector value added was obtained from Africa Development Bank (AFDB) data portal. . The relationship between TFP and $R\&D$ is hypothesized to be positive. Temperature and rainfall affect the growth and development of any agricultural crops and the effectiveness of various farming activities (Villavicencio et. al., 2013). In line with previous studies (Asseng et al., 2011; Ajetomobi, 2012) we measured temperature as the yearly average while rainfall was computed as the annual total precipitation. However, in order to account for the variation over the years, we used their anomalies in the regression model. The anomalies is calculated as the difference between a year average and the average over more than 30 years covered by this study. The climate data were collected from the World Bank Climate Data Portal. There is a negative but significant relationship between efficiency of water use and evapotranspiration (Zhong et al., 2019; Kaminski et. al., 2012). Evapotranspiration is usually measured as the average rainfall over the whole month, quarter or year. Annual average was used in this study.

Based on (4) we have to obtain TFP in order to examine climate change impacts on agricultural productivity for the five SACU countries. Coelli et al., (1998) defined four approaches to measure TFP. These methods are: production function method, the use of growth accounting index, stochastic frontier approach and Malmquist productivity index. In this study, Malmquist productivity index based on Data Envelopment Analysis (DEA) was employed. Among others, the advantages of the methods include (i) it does not require any econometric assumptions, (ii) it is based on linear programming which build a piece-wise linear surface over the production data points and (iii) does not require information on cost or revenue shares to aggregate inputs or outputs (Hjalmarsson and Veiderpass 1992, Charnes, Cooper, and Rhodes 1978; Lovell and Schmidt 1988; Schmidt 1986; Bauer 1990; Seiford and Thrall 1990; Greene 1993; Coelli et al. 2010, and Ajetomobi 2012). A common criticisms of DEA has been its inability to account for the measurement error and to test for significance of the efficiency measures. In order to address the problem, Fare and Grosskopf (1995) proposed some statistical tests which have subsequently made DEA a powerful tool for efficiency analysis.

For this study, Fare et al, 1994 output distance function is assumed. Given that for each time period t = 1, 2, …, T, $x_t \in R_+^N$ and $y_t \in R_+^M$ denote respectively an 1 × N input vector and an 1 × M output vector. The set of production possibilities is given by the closed set,

$$s_t = \{(x_t, y_t): x_t \; can \; produce \; y_t\} \quad (6)$$

The technology is assumed to have the standard properties such as convexity and strong disposability (Färe et al, 1994). The output sets are defined in terms of s_t as

$$p_t(x_t) = \{y_t: (x_t, y_t) \in s_t\} \quad (7)$$

According to Shephard (1970), the output distance function in t for any productivity unit would be

$$d_0^t(x_t, y_t) = inf\left\{\theta: \left(\frac{y_t}{\theta}\right) \in p_t(x_t)\right\} \quad (8)$$

The subscript "o" stands for "output oriented". The distance function was the Farrell's reciprocal measurement (Farrell, 1957). This distance function represents the smallest factor, θ by which an output vector y_t is deflated so that it can be produced with a given input vector x_t under period t's technology. The function $d_0^t(x_t, y_t)$ provides a standardized average of distance of a unit in the period t to frontier t of production set when inputs are constant. It will take the value of less than 1 if the output vector y is an element of the feasible production set. It will take the value of 1 if y is located on the outer boundary of the feasible set and value of greater than 1 if y is located outside the feasible production set. The productivity change using technology of period t as reference is as follows

$$M_0^t(x_t, y_t, x_{t+1}, y_{t+1}) = \left[\frac{d_0^t(x_{t+1}, y_{t+1})}{d_0^t(x_t, y_t)}\right] \quad (9)$$

In like manners, we can measure the Malmquist productivity index with period t+1 as references as follows

$$M_0^{t+1}(x_t, y_t, x_{t+1}, y_{t+1}) = \left[\frac{d_0^{t+1}(x_{t+1}, y_{t+1})}{d_0^{t+1}(x_t, y_t)}\right] \quad (10)$$

To avoid choosing arbitrary period as reference, Fare et al., (1994) specifies the Malmquist productivity index as the geometric mean of the above two indices (Malmquist, 1953).

$$M_0(x_t, y_t, x_{t+1}, y_{t+1}) = \left[\frac{d_0^t(x_{t+1}, y_{t+1})}{d_0^t(x_t, y_t)} * \frac{d_0^{t+1}(x_{t+1}, y_{t+1})}{d_0^{t+1}(x_t, y_t)}\right] \quad (11)$$

Equation (11) can be decomposed into two components. The first is the efficiency change (EFFCH) index which measures the output-oriented shift in technology between two periods. When it is greater or less than one, there exist some improvements or deterioration in the relative efficiency of this unit. The second component is the technological change (TECHCH). TECHCH is the geometric average of components and technical change between period t+1 and t. The first component in TECHCH measures the position of unit t+1 with respect to the technologies in both periods. The second component also estimates this for unit t. If the TECHCH is greater (or less) than one, then technological progress (or regress) exists

$$EFFCH = \frac{d_0^{t+1}(x_{t+1}, y_{t+1})}{d_0^t(x_t, y_t)} \quad (12)$$

$$TECHCH = \left[\frac{d_0^t(x_{t+1}, y_{t+1})}{d_0^{t+1}(x_{t+1}, y_{t+1})} * \frac{d_0^t(x_t, y_t)}{d_0^{t+1}(x_t, y_t)}\right]^{1/2} \quad (13)$$

.

The TFP change is the product of EFFCH and TECHCH.

In order to account for the return to scale properties of the technology, Grifell – Lovell (1995) use a one input, one output example to illustrate that Malmquist index may not correctly measure TFP changes when Variable Return to Scale (VRS) is assumed for the technology. Hence, Constant Return to Scale is imposed upon the technology used to estimate the distance functions for the calculation of the Malmquist index for this study. The envelopment of Decision Making Units (DMU) can be estimated through Linear Programming (LP) methods to identify the best practice for each DMU. Assuming CRS technology in their analysis, the required linear programming equations are:

$$[d_o(x^{k*}, y^{k*})]^{-1} = max\theta^{k*} \quad (14)$$

Subject to

$$\sum_{k=1}^{N} z^k y_j^k \geq y_j^k \theta^{k*} \; j = 1.2 \ldots . j$$

$$\sum_{k=1}^{N} z^k x_h^k \geq x_h^{k*} \; h = 1.2 \ldots . h$$

$$z^k \geq 0, k = 1, 2 \ldots ., n$$

Where k is the set of countries, j is the set of outputs, h is the set of inputs, z^k is the weight of the kth country data and θ is the efficiency index which is equal to 1 if country k^* is efficiently producing the output vector.

In order to estimate DEA-based Malmquist index, a panel dataset for the five SACU countries (Botswana, Eswatini, Lesotho, Namibia and South Africa) was collected for the time period between 1981 and 2018. Data on traditional agricultural inputs (land, labor, fertilizer, livestock and machinery) and output were obtained from the African Information Highway (AIH) portal (dataportal.opendataforafrica.org).

The agricultural output was the FAO index of agricultural production measured as the relative level of the aggregate volume of agricultural production for each year in comparison with the base period 2004-2006. Agricultural land refers to the total arable and permanent crops and pastures expressed in thousands hectares. Agricultural labour force is the economically active population in agriculture. This include part of the economically active population that are engaged in or seeking work in agriculture, hunting or forestry. Livestock is measured as the weighted average of the number of animals in farms presented in cattle equivalents. Machinery is defined as the total number of agricultural tractors while fertilizer is defined as various fertilizers (N, P, K and compounds) used in agriculture by a country. The time reference for fertilizer consumption is generally the crop year (July through June). Data processing were supported by the following r software platform and packages: rstudio , table1, ExpanDar, plm, and stargazer.

IV. RESULTS AND DISCUSSION

Descriptive Statistics

Table 3 shows the descriptive statistics of the variables used in the estimation of the Malmquist TFPA based on DEA method and subsequent regression analysis. Botswana has the highest agricultural output in the region followed by Lesotho. The least output was recorded in Namibia. This is not surprising because the country has the least amount of rainfall on the average within the region over the period covered in the analysis. Table 3 shows that Eswatini has the highest amount of rainfall followed closely by Lesotho. Botswana is the hottest within the SACU region with an average temperature of 22.2oC while Lesotho has the lowest average temperature (13.4oC). In respect of agricultural land use in hectares, Namibia is next to South Africa on the average over the analysis period. Eswatini has the highest livestock production but next to the Republic of South Africa in terms of number of tractors available for agricultural production. South Africa has the highest number of economically active population in agriculture in the region followed by Lesotho. In terms of fertilizer consumption, Eswatini is next to South Africa. South Africa has the highest average public spending on Agricultural Research and development followed closely by Botswana. Lesotho has the lowest expenditure on research and development in the region.

Table 3: Descriptive Statistics: Means of Variables: 1980-2018

Variable	Botswana	Eswatini	Lesotho	Namibia	SA
Output	100	95.8	98.6	86.3	98.3
Land	25900	1240	2310	38800	96500
Tractor	3370	12400	2290	2990	89900
Livestock	93.9	99.7	87.2	89.7	92.8
Labour	263000	138000	328000	266000	1440000
Fertilizer	4910	49100	4960	3450	796000
Temp.	22.2	20.4	13.4	20.9	18.1
Rain	371	801	732	263	461
EPT	30.9	66.7	61	21.9	38.4
R&D	8150	2580	1180	13500	123000

NOTE: Temp means temperature; Rain rainfall; EPT evapotranspiration; R&D agricultural research and development expenditure; R&D figures are in thousands

Climate Trend

The observed trend in average temperature and rainfall for 1981 – 2018 for the SACU countries are presented in Figure 1 The trends are characterized by high degree of geographic variability across the countries. Botswana and Namibia show more increasing trend in average temperature than other countries in the region. The two countries are expected to experience worse heat stress than other countries. Like average temperature, high spatial variability are also observed across the SACU countries. The trend in Eswatini and Lesotho are generally higher in magnitude than other countries in the region over the entire analysis period. Namibia recorded lowest amount of rainfall in the region followed by Botswana. The climate trends are hypothesize to have either positive or negative implication on the countries' agricultural productivity growth depending on how they affect crop yields, irrigation management, crop water demand, risks of pests and diseases, length of growing season and soil management practices.

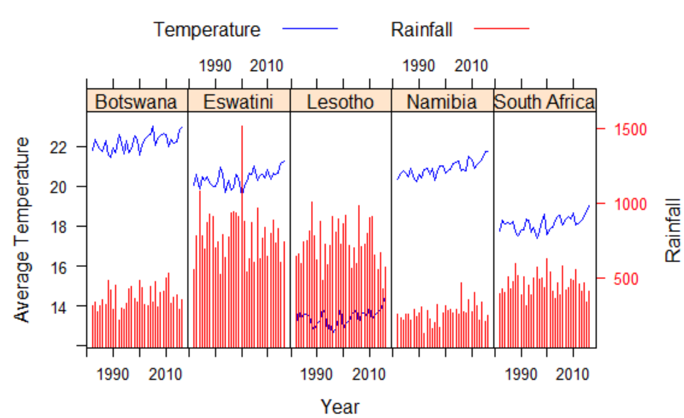

Figure 1: Trend in SACU Countries' Temperature and Rainfall

TFP and Its Decomposition Across SACU Countries

Given differences in the SACU countries' contribution of agriculture to GDP and socio-economic indicators shown in

Tables 1 and 2, agricultural productivity growth in the countries are also expected to vary considerably. The results of the TFP and its decomposition across the countries are presented in Table 5.

Table 5: Agricultural TFP of SACU Countries

Country	EFFCH	TECHCH	TFPCH
Botswana	1.001	1.061	1.061
Eswatini	1.000	0.997	0.997
Lesotho	1.000	1.156	1.156
Namibia	1.012	1.157	1.268
South Africa	1.388	1.022	1.327
Mean	1.080	1.079	1.162

Note: EEFCH is efficiency change, TECHCH is technical change, and TFPCH is total factor productivity change

Over the analysis period (1981-2018), all the countries within SACU made progress in their agricultural productivity growth apart from Eswatini. The growth varies from 6.1% in Botswana to 32.7% in South Africa. The outstanding agricultural productivity growth of South Africa relative to other SACU nations is not a surprise because the economies of other SACU countries generally depend on South Africa for survival. Apart from South Africa and Eswatini, agricultural productivity growth in the region is more driven by technological progress than efficiency change. The main reason for relatively low agricultural productivity growth in Eswatini may be because it is a landlocked country which depend more on food imports than production. Another likely reason may be because the farmers in the country grow limited number of arable and permanent crops and lack of land tenure security. Most Eswatini farmers operates on Swazi Nation Land (SNL) where they do not have title deed. Hence, they have little or no access bank loan, irrigation and productivity increasing technologies. About 60% of the farmers largely grow maize and vegetables.

Results of the Panel Regression Model

The results of the panel regression are presented in Table 5 while the diagnostic tests are shown in Table 6. The null hypothesis that the variance across the SACU countries is zero is not rejected by the Langrange Multiplier (LM) test. Also, the F-test for time-fixed effects show that there is no need to use time-fixed effects. The results reported is therefore based on the Ordinary Least Square (OLS) estimates of the pooled data in column 2 of Table 5. The results show that both temperature and rainfall anomalies have negative but significant effects on the total factor productivity growth of agriculture in the region. The results imply that the higher the temperature and rainfall anomalies, the lower the agricultural productivity growth in SACU region.

Table 6: Climate Effects on TFP

Variables	OLS	One-way FE	Two-way FE
Temperature	-0.02 (-2.35)*	0.20 (2.63)*	-0.76 (-1.98)*
Rainfall	-0.08 (-3.11)*	-0.004 (-0.90)	-0.001 (-1.00)
R & D	-0.06 (-1.54)	-0.03 (-0.48)	-0.13 (-2.15)*
Intercept	1.31 (13.84)*	No	No
Country-FE	No	Yes	Yes
Time-FE	No	No	Yes
R Squared	0.20	0.20	0.30
F – Value	7.30*	113.66*	121.89*

NOTE: FE means Fixed- Effect

V. CONCLUSION

The main purpose of this study is to investigate possible impact of climate change on regional agricultural total factor productivity in SACU member nations, namely, Eswatini, Lesotho, Namibia, Botswana and South Africa. To do this, the analysis was conducted in two phases using time series data between 1981 and 2018. In phase one, agricultural TFP growth in the region was estimated and decomposed with Data Envelopment Analysis (DEA) Mamquist productivity measure. In the second phase, a panel regression model was used to investigate the relationship between the estimated TFP growth and climate variables while controlling for the effects of research and development expenses. The policy implications are as follows. Firstly, over the analysis period (1981-2016), all the countries within SACU made progress in their agricultural productivity growth apart from Eswatini. However, the TFPA trend is fluctuating across the five countries within SACU. Secondly, the results of the panel data models show that the effect of research and development investment on agricultural productivity growth in the region is still insignificant. Lastly, the effects of climate change as measured by temperature and rainfall anomalies are negative and significant. Based on the findings, we would like to suggest the following recommendations: Stakeholders in SACU agricultural sector should take proactive steps on climate change adaptation options. The governments for instance, can take keen interest in financing development of new crop varieties and livestock breeds that can withstand heat stress. SACU can coordinate the activities via a Common Agricultural Policy (SACUCAP). Another possible way to mitigate the effects of the climate anomalies is to promote weather-based insurance and take the issue of climate change early warning systems very serious.

REFERENCES

1. Ajetomobi J. O. (2012) *Total Factor Productivity of Agricultural Commodities in the Economic Community of West African States: 1961-2005*. AERC Research Paper 253, African Economic Research Consortium, Kenya.
2. Ajetomobi, J. O. (2016). Effects of weather extremes on crop yields in Nigeria. *African Journal of Food, Agriculture, Nutrition and Development*, 16(4), 11168–11184.
3. Asseng, S., I. Foster, & N. C. Turner (2011). The Impact of Temperature Variability on Wheat Yields. *Global Change Biology* 17: 997-1012
4. Bauer, Paul W. (1990). Recent Developments in the Econometric Estimation of Frontiers, *Journal of Econometrics*, 46: 39-56
5. Brooks, N., Anderson, S., Ayers, J., Burton, I., & Tellam, I. (2011). *Tracking adaptation and measuring development*. International Institute for Environment and Development (IIED), London.
6. Charnes, A., Cooper, W.W. & A. Rhodes 1978, 'Measuring efficiency of decision making units',

European Journal of Operational Research, 2: 429–444.
7. Coelli, T. J., and D .S. P. Rao (2005). Total factor productivity growth in Agriculture: A malmquist Index Analysis of 93 countries, 1980 – 2000, *Agricultural Economics* 32(s1): 115 – 134.
8. Coelli, E. G., Rao, D. S. P. and G. E. Battese (1998*). An Introduction to Efficiency and Productivity Analysis,* Kluwer Academic Publishers, Boston/Dordretch/London.
9. Färe, R., S. Grosskopf, and C.A.K. Lovell (1995). *Production Frontiers*, Cambridge: Cambridge University Press, Cambridge UK
10. Fare, R;S, Grosskopf, M. Norris and Z. Zhang (1994). Productivity growth, technical progress and efficiency change in industrialized countries. *American Economic Review* 84: 66 – 83.
11. Farrell M J. (1957). The measurement of productive efficiency, *Journal of the Royal Statistical Society,* 120(3):252-290
12. Greene, W. H. (1993). "The Econometric Approach to Efficiency Analysis," in Harold O. Fried, C.A. Knox Lovell, and Shelton S. Schmidt (eds.), *The Measurement of Productive Efficiency: Techniques and Applications* , New York, NY: Oxford University Press.
13. Grifell-Tatje´ and Lovell, C. A. K. (1995) A note on the Malmquist productivity index, *Economic Letters*, 47, 169–75.
14. Lovell, C.A.L. and Schmidt, P. (1988) "A Comparison of Alternative Approaches to the Measurement of Productive Efficiency" in Dogramaci, A., Färe, R. (eds.) *Applications of Modern Production Theory: Efficiency and Productivity*, Kluwer: Boston.
15. Hjalmarsson, L and Veiderpass (1992). Productivity in Swedish electricity retail distribution. *Scandinavian Journal of Economics* 94 (supplement): 193-205
16. Hu, Z. Z. & L. Jiang (2019). Impact of Climate Change on Agricultural Total Factor Productivity Based on Spatial Data model. Evidence from China. *Sustainability* 11: 1-17
17. Huffman, W. E., & Evenson, R. E. (2006). Do formula or competitive grant funds have greater impacts on state agricultural productivity? *American Journal of Agricultural Economics*, 88(4), 783–798.
18. Just, R. E., & Pope, R. D. (1979). Production function estimation and related risk considerations. *American Journal of Agricultural Economics*, 61(2), 276–284.
19. Kalamba, M. (2015). South Africa Struggling Agricultural Sector: What went wrong 20 years ago. https://theconversation.com/south-africas-struggling-agricultural-sector-what-went-wrong-20-years-ago-45171
20. Knox, J., Hess, T., Daccache, A., & Wheeler, T. (2012). Climate change impacts on crop productivity in Africa and South Asia. *Environmental Research Letters*, 7(3), 034032.
21. Liang, X.-Z., Wu, Y., Chambers, R. G., Schmoldt, D. L., Gao, W., Liu, C., … Kennedy, J. A. (2017). Determining climate effects on US total agricultural productivity. Proceedings of the National Academy of Sciences, 114(12), E2285–E2292.
22. Lovell, C.A.L. and Schmidt, P. (1988) A Comparison of Alternative Approaches to the Measurement of Productive Efficiency in Dogramaci, A., Färe, R. (eds.) *Applications of Modern Production Theory: Efficiency and Productivity*, Kluwer: Boston
23. Mendelsohn, R., Dinar, A., & Sanghi, A. (2001). The effect of development on the climate sensitivity of agriculture. *Environment and Development Economics*, 6(1), 85–101.
24. Mendelsohn, R., Nordhaus, W. D., & Shaw, D. (1994). The impact of global warming on agriculture: a Ricardian analysis. *The American Economic Review*, 753–771.
25. Mullen, J. D., & Cox, T. L. (1995). The returns from research in Australian broadacre agriculture. *Australian Journal of Agricultural Economics*, 39(2), 105–128.
26. Schlenker, W., & D. B. Lobell. (2010). Robust negative impacts of climate change on African agriculture. *Environmental Research Letters*, 5(1), 014010.
27. Schmidt, Peter (1986). On the Statistical Estimation of Parametric Frontier Production Functions, Review of Economics and Statistics: 238-239. *Administration Research and Theory*, 5(4): 403-428.
28. Seiford, L.M., and Thrall, R.M. (1990) Recent Developments in DEA: The Mathematical Programming Approach to Frontier Analysis, *Journal of Econometrics*, 46, pp. 7-38.
29. Seiford I. S. (1995). *Data Envelopment Analysis: Theory, Methodology and Applications*. Amsterdam: Kluwer Academic Publisher
30. Tayebi, Z., & Fulginiti, L. E. (2016). Agricultural productivity and climate change in the greater Middle East.
31. Torvanger, A., Twena, M., & Romstad, B. ard. (2014). Climate change impacts on agricultural productivity in Norway. Climate Change Effect on Crop Productivity, 459.
32. Zhong, Z., Hu, Y., & Jiang, L. (2019). Impact of Climate Change on Agricultural Total Factor Productivity Based on Spatial Panel Data Model: Evidence from China. *Sustainability*, 11(6), 1516.

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