“The impact of climate change on agricultural output in South Africa (1997-2012)”

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The impact of climate change on agricultural output in South Africa (1997-2012)

Abstract

South Africa has shown major interest in the climate change discourse since the Kyoto Protocol in 1997. Climate change has moved from an issue of environmental concern to an issue of commercial significance. The purpose of this study was to investigate the impact of climate change on agriculture output in South Africa. The impact of climate change on output is examined in this study using the ordinary least squares (OLS) method. The estimated econometric model regresses temperature, rainfall, labor and capital on GDP in the agricultural sector. The results suggest that there is a negative relationship between climate change and agricultural output in South Africa.

Keywords: impact, OLS, South Africa, climate change, agricultural output.
JEL Classification: Q1, Q2, Q4, Q5.

Introduction

South Africa has shown major interest in the climate change discourse since the Kyoto Protocol in 1997. Climate change has moved from an issue of environmental concern to an issue of commercial significance. Hence climate change has become one of the top issues that the government tries to address.

At the same time when South Africa emerged from the apartheid era in 1994 it had an urgent need to complement its political liberation and its openness to global trade and investment with economic growth that would benefit all members of the population. This democratic transition consequently created expectations of a turnaround in the country's economic performance. Hence since then to date South Africa has made it one of its macroeconomic policies to accelerate growth and curtail poverty. As this takes place, emissions of greenhouse gases (GHG) rise, which, in turn, leads to considerable changes in the climate. South Africa happens to be a highly energy-intensive economy and its reliance on coal-based electricity makes the country the 14th highest carbon dioxide emitter in the world, with per capita emissions being higher than those of many European countries and more than 3, 5 times higher than the average for developing countries (Winkler, 2007). These carbon dioxide emissions as stated before contribute to climate change.

This intersection between energy consumption and economic growth is therefore particularly salient when analyzed in relation to the three metropolitan cities in South Africa (Johannesburg, Thekwini and Cape Town). Not only do these three cities contribute the most to South Africa's economic output, but in doing so, they are also the country's biggest emitters of greenhouse gases (GHG) which contribute to climate change in South Africa and globally. Chown (2011) also alludes that South Africa has long relied on coal to produce cheap electricity; this cheap, but dirty fossil fuel has driven South Africa's economy for many decades, and has, alongside this development, created many thousands of jobs both in the mining and energy sector. The high emissions of GHG resulting from the coal have become of major importance. Consequently the 2011 Eastern Cape Provincial Climate Change Summit focused on many of the key issues, in particular how to deploy renewable energy technology to lessen South Africa's change reliance on polluting power sources which are now undeniably at the centre of the climate storm. In addition, there are commitments that President Zuma and the Cabinet made in Copenhagen in 2009, and were reaffirmed at the climate talks in Cancun in 2010.

In South Africa, climate change is expected to result in higher temperatures, higher CO_2, more sporadic and low rainfall patterns and frequent droughts. Superimposed on the country's already scarce water resources, these impacts are expected to affect all sectors of the economy. South Africa is particularly vulnerable to climate change because of its dependence on climate-sensitive economic sectors and high levels of poverty. The poor are disproportionately affected, as they rely on sectors that will be directly affected by climate change: agriculture, biodiversity, ecosystems and water supplies.

Agriculture is extremely vulnerable to climate change. Higher temperatures eventually reduce yields of desirable crops while encouraging weed and pest proliferation (Nelson et al., 2009). Changes in precipitation patterns increase the likelihood of short-run crop failures and long-run production declines (*ibid*). Although there will be gains in some crops in some regions of the world, the overall impacts of climate change on agriculture are expected to be negative, threatening global food security.

This study acknowledges the significant ramifications that direct climate change impacts could have on the South African agricultural output. Based on such a background this research therefore intends to reveal the calculated impact that climate change already has on agricultural output in South Africa, in a bid to envision policy makers to come up with mitigation strategies to reduce the impact that climate change has on agricultural output which heavily determines the country's food security.

In Section 1 the overview of agriculture and climate is given, and Section 2 presents the methodology used in this study. Section 3 presents the results analysis. Lastly, Final Section gives a conclusion and recommendations for the study.

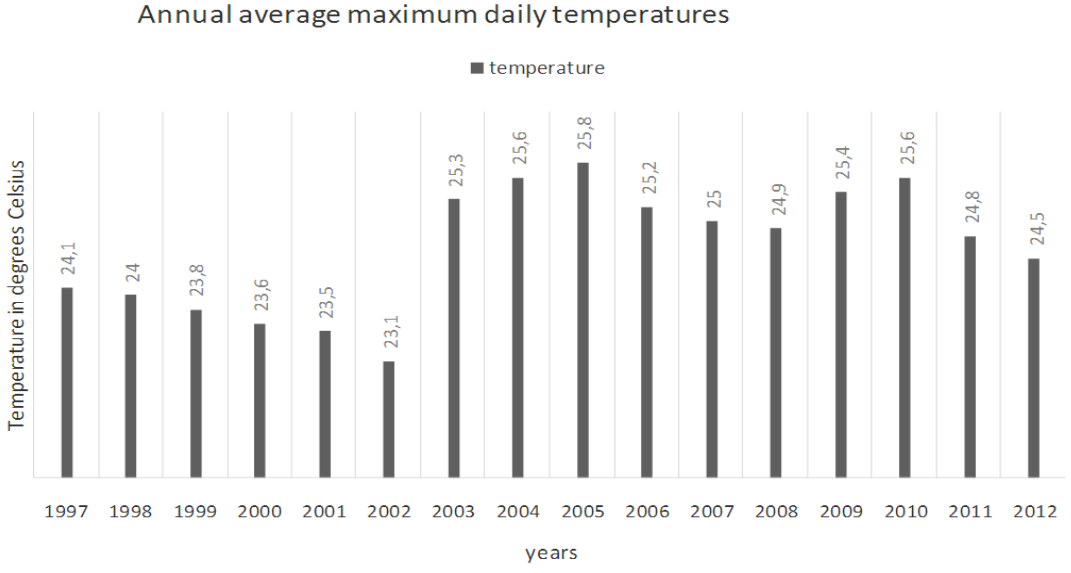
1. Overview of trends in agriculture sector and climate

The United Nations Framework Convention on Climate Change (UNFCCC, 2006) defines climate change as a change in climate that is attributable directly or indirectly to human activity that alters atmospheric composition. This leads to changes in the climate system, such as climate warming and more frequent and intense extreme weather events. South Africa is susceptible to climate change principally through changing rainfall and temperature patterns and extreme weather events (as evidenced by the responses from participants (selection of quotes) taken out of a series of focus group discussions conducted by UNICEF South Africa with children at the national level and in the Limpopo and KwaZulu-Natal provinces.

The country's climate is generally warm, with sunny days and cool nights. Rainfall mostly occurs in summer (November to March), with winter rainfall (June to August) in the south-west around the Cape of Good Hope. Temperatures are more influenced by variations in elevation, terrain and ocean currents than latitudes. For example, the average annual temperature in Cape Town is 17°C and in Pretoria 17.5°C, although these cities are separated by almost ten degrees of latitude (Palmer & Ainslie, 2002).

1.1. Temperature. Kruger and Shongwe (2004) analyzed climate data from 26 weather stations across the country. Of these, 23 showed that the average annual maximum temperature had increased, in 13 of them significantly. Average annual minimum temperatures also showed an increase, of which 18 were significant. Broadly, their analysis indicates that the country's average yearly temperatures increased between 1960 and 2003. It was also suggested by World Bank (2010) that South Africa has been getting hotter over the past four decades with average minimum monthly temperature at 13 degrees Celsius and average maximum monthly temperature at 26 degrees Celsius. There has also been an increase in the number of warmer days and a decrease in the number of cooler days.

This study however analyzes the annual average daily maximum temperature trends since 1997 to 2012. Using data obtained from South African Weather Services a graphical analysis of the trend will help to unpack the changes in daily temperatures that have occurred in South Africa since 1997. The graph is given in Figure 1.

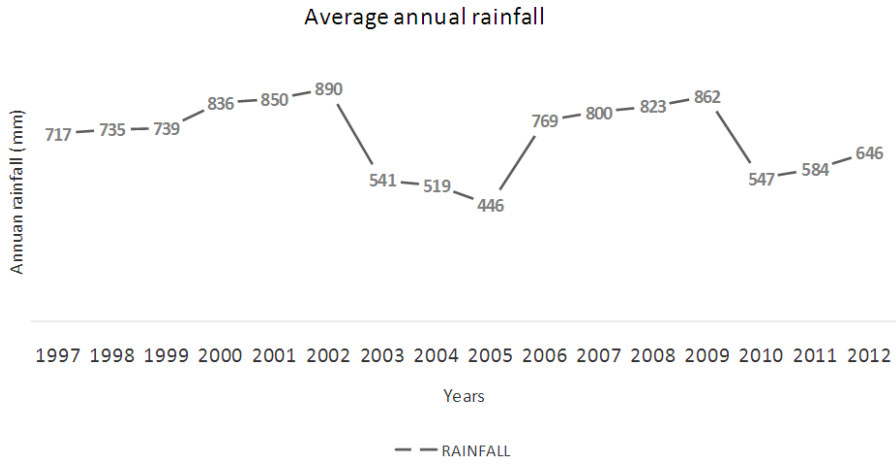


Source: South African weather services (2013).

Fig. 1. Daily maximum temperature (^{o}C) for South Africa

As shown above South Africa's average daily maximum temperatures seem to have increased since 1997. Temperatures during the first six years (period of 1997 to 2002) were in the region of 24 degrees Celsius and below. However we see the nation warming up gradually as temperatures increase way above 24 degrees Celsius in years following 2002 (i.e. 2002 to 2012). South Africa has thus recorded approximately an average of 26.3 degrees Celsius during the years of 1997 to 2012. It is therefore conclusive that the graph supports conclusions by Kruger and Shongwe (2004) that indeed South Africa's maximum temperatures are increasing and consequently leading to South Africa warming up.

1.2. Rainfall. National Department of Agriculture (2011) alludes that the average annual rainfall of 450mm per year is highly below the world's average of 860mm, while evaporation is comparatively high. Moreover, only 10% of the country receives an annual precipitation of more than 750mm and more than 50% of South Africa's water resource is used for agricultural purposes. Figure 2 shows the annual rainfall.

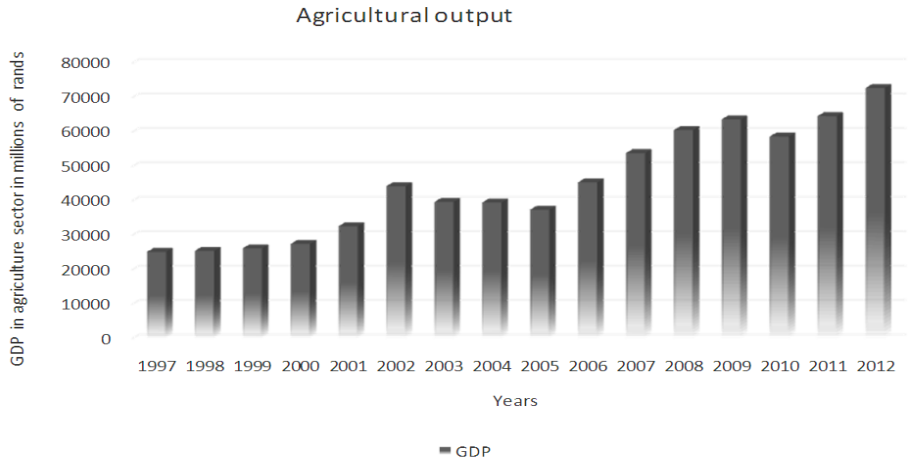


Source: South African weather services (2013).

Fig. 2. Annual rainfall in (mm) for South Africa

The average annual rainfall in 2003, 2004, 2005, 2010, 2011 and 2012 averaged 541, 519, 446, 547, 584 and 646 respectively. These amounts were lower when compared to the period of 1997 to 2002 (717, 735, 739, 836, 850 and 890 respectively) and this period was accompanied by lower temperatures as shown in Figure 2 above. This is evidence South Africa's climate is changing. It is becoming hotter and drier. The highest rainfall recorded amongst the years studied is 2002 with rainfall averaging a little above 890 mm and yet for the last three years (2010 to 2012) the rainfall has only averaged approximately 590 mm.

1.3. Trends in agriculture sector. In South Africa, the agricultural sector plays a significant role in the country's economy. Anecdotal evidence suggests that climate change could lead to a fall of about 1.5% in the country's GDP by 2050 a fall roughly equivalent to the total annual foreign direct investment in South Africa at present (DEAT, 2006). Figure 3 shows the agricultural output.



Source: Statistics South Africa (2013).

Fig. 3. Agriculture output in South Africa (1997-2012)

There is a gradual increase in GDP for the first six years that is the period from 1997 to 2002, followed by a dip from 2003 to 2005. The highest output value of 72 731 million Rands was recorded in 2012.

2. Methodology

The econometric technique used in this study is adopted from Barrios, Ouattara and Strobl (2008) where the simple regression model was expressed in the following form:

$$Y_{i,j} = AL^{\beta_1}V^{\beta_2}F^{\beta_3}K^{\beta_4}M^{\beta_5}PRC^{\beta_6}TEMP^{\beta_7}e^{\varepsilon},.. \quad ....(1)$$

where Y is agriculture output, V is livestock input, L is labor input, F is fertilizer input, K is capital input, M is land input, PRC is precipitation, $TEMP$ is temperature, A is productivity parameter, e is error term.

In order to investigate the impact of climatic changes on agricultural production in Sub-Saharan Africa (SSA) relative to other developing countries Barrios, Ouattara and Strobl used the Cobb Douglas function above (i.e. equation 1). However, this study employs the same Cobb Douglas function but will differ in some variables as GDP of the agriculture sector will be used as a measure of economic performance of the sector. Barrios et al. (2008) made a comparison amongst countries; hence it was paramount for them to factor in land as different countries will have different effects due to different land. Since this study is only for South Africa and to show if climate change is affecting agriculture output we can do without many inputs included by Barrios.

This study estimates the following model:

$$AgGDP = f\left(\beta_0 L^{\beta_1}K^{\beta_2}T^{\beta_3}R^{\beta_4}\right),$$

where: $AgGDP$ is output in the agricultural sector, L is labor input, K is capital input and T is temperature, R is rainfall.

Therefore this study estimates the following regression model:

$$\log AgGDP = \beta_0 + \beta_1 \log L_t + \beta_2 \log K_t + \beta_3 \log T_t + \\ +\beta_4 \log R_t + D_t + \mu. \quad (2)$$

In order to avoid any form of misconception of empirical results, a description of all variables that appear in the estimated equation is provided:

- log$AgGDP$. Logarithm of output in the agriculture sector measured by GDP of the agriculture sector.
- logL_t: logarithm of labor input. It involves the labour productivity in the agriculture sector of South Africa.
- logK_t: logarithm of capital input. It involves data on capital productivity in South Africa's agricultural sector.
- logT_t: logarithm of temperature. Used as auxiliary climatic change variable and the daily maximum temperatures in degrees Celsius are used.
- logR_t: logarithm of rainfall. Used also as an auxiliary climate change variable.
- μ: This represents the error term. The error term represents the influence of the omitted variables in the construction of the data.
- D: Dummy variable for drought periods.
- β_0, β_1, β_3, and β_4: Parameter estimates or coefficients of the explanatory variables.

2.1. Data sources. The study used data on temperature and rainfall which was obtained from South African Weather Services (SAWS). Also data for labour productivity and capital productivity was obtained from DAS, Statistics South Africa and other official publications including journals. Data for all GDP of the agriculture sector were obtained from Statistics South Africa as well. The data used covered the period 1997-2012.

2.2. The expected priori. Economic growth in a country can be ascribed either to increased employment or to more effective work by those who are employed, hence, the expected sign of the coefficient of labor, β_1 is positive. This is because as labor productivity increases output in the agriculture sector will increase. Also, according to economic theory the capital input has a positive relationship with agricultural output. As the capital input increase output in the agricultural sector also increases, thus a positive sign of the β_2 coefficient is expected. The expected sign of the β_3 coefficient of temperature is negative since agricultural output decreases with an increase in temperatures which is a characteristic of climate change in South Africa. In consequence a negative sign of the β_3 coefficient is expected. However rainfall is positively or negatively related to output since an increase in rainfall is associated with an increase in output yet on the other hand it can result to a decrease due to excessive rainfall that damages the crops and affect the agricultural output. As a result a positive or negative sign for β_4 is expected. The DUM variable takes 1 for drought 0 otherwise.

2.3. The augmented Dickey-Fuller test. The null hypothesis of a unit root is rejected in favor of the stationary alternative; in each case the test statistic is more negative than the critical value. Alternatively put in absolute terms if the calculated value is greater than the critical, we reject the null hypothesis that the series have unit root, thus confirming that the series is stationary. The results of the ADF test are shown on Table 1.

Table 1. ADF test

Augmented Dickey-Fuller					
Variable		Intercept	Trend and intercept	None	Order of integration
LOGGDP		-0.759619 -4.209310**	-3.810818 -3.98710*	3.55880 -2.498615**	I(1) I(0)
LOGL		-0.175713 -4.655600**	-1.515504 -3.926625*	1.636740 -3.835833**	I(1) I(0)
LOGK		-0.218417 -3.462549*	-0.138539 -3.875768*	-0.402087 -3.098159**	I(1) I(0)
LOGT		-1.612835 -3.431710*	-1.717329 -3.886963**	0.133808 -3.562882**	I(1) I(0)
LOGPRC		-3.362741* -3.555087*	-3.302113 -3.978929*	-0.178008 -3.799701**	I(1) I(0)
Critical values	1%	-4.121990	-4.992279	-2.728252	
	5%	-3.144920	-3.875302	-1.966270	

Notes: Values marked with * represent a stationary variable at 5% significance level and ** represent a stationary variable at 1% significance level.

2.4. Normality test. The Jarque-Bera is 1.498571 and the Probability is 0.472704. Thus, the Jarque-Bera statistic is not significant at 5 percent significance level we fail to reject the null hypothesis and conclude that the residuals are normally distributed, hence the histogram should be bell-shaped. Therefore, the null hypothesis of a normal distribution was not rejected.

2.5. Serial correlation test. For the Breusch-Godfrey Serial Correlation LM Test the *p*-value of the F statistic is 0.946466 which is not significant at 5% t implying that we fail to reject the null hypothesis of the none-existence of serial correlation. We therefore conclude that there is no serial correlation amongst the residuals.

2.6. Heteroscedasticity. The null hypothesis for the White test is homoscedasticity (meaning there is no Heteroscedasticity) and if we fail to reject the null hypothesis then we have homoscedasticity. Heteroscedasticity Tests showed the F-statistic of 0.521881 and the Prob. of 0.122169 which means at 5% level we fail to reject the null hypothesis since F statistic is greater than F critical. Therefore the residuals are homoscedastic.

3. Interpretation of results

This section assesses each explanatory variable independently to explain its impact on the dependent variable. Table 2 shows the results of the OLS regression.

Table 2. OLS regression

Variable	Coefficient	t-statistic	Prob.
C	0.055193	5.989063	0.0002***
Log*T*	-0.803173	-0.977742	0.3537
Log*R*	0.150436	1.533317	0.1596
Log*L*	-0.634809	-2.610277	0.0283**
Log*K*	0.312653	2.900110	0.0176***
D	-0.049968	-2.950522	0.0162***
R-squared	0.825797	F-statistic	8.532781
S.E. of regression	0.025542	Durbin Watson	2.138819

Notes: Values marked with *represent a stationary variable at 5% significance level and **represent a stationary variable at 1% significance level.

The estimated equation can now be represented using the regression results as follows:

$$\log Y = 0.055193 - 0.634809 \log L_t + 0.312653\ logK_t - 0.803173 \log T_t + 0.150436 \log R_t - 0.049968 + \mu.$$

To start with, the -0.977742 *t*-statistic corresponding to temperature is less than the standard critical value of *t* of |2| thus showing that Log*T* as an explanatory variable is statistically insignificant in explaining the changes in the dependent variable, output. The 0.3537 *p*-value corresponding to temperature indicates that changes in the variable are statistically insignificant in explaining changes in overall output at 5 percent level of significance. Theoretically there is a negative relationship between temperature and agricultural output. This relationship between Log*T* and Log*GDP* reinforces the hypothesis of this study which argues that there is a negative relationship between temperature and output.

The *t*-statistic 1.533317 corresponding to the rainfall coefficient is less than |2| the standard critical value of *t* reflecting that this explanatory variable does not account for much of the changes in output. The *p*-

value 0.1596 shows that the rainfall is statistically insignificant in explaining changes in output at five percent level of significance. The coefficient for rainfall is 0.150436 and it has a positive sign which shows that there is a positive relationship between LOGR and LOGGDP where a unit increase in LOGR results in approximately 34.4 percent increase in LOGGDP and vice-versa. This result is consistent with theory that argues that an increase in the rainfall will lead to an increase in output in agriculture sector.

However, the -2.610277 *t*-statistic corresponding to labor employed is greater than the standard critical value of *t* of |2| thus showing that LOGL as an explanatory variable is statistically significant in explaining the changes in the dependent variable, output (LOGGDP). In other words, LOGL is accounting for much of the changes in LOGGDP. The *p*-value for labor employed is 0.0283 reinforcing that this explanatory variable is statistically significant in explaining changes in output at five percent level of significance.

The capital (LOGK) *t*-statistic of 2.900110 is more than the standard critical value of *t* of |2| which also entails the statistical significance of LOGK in explaining changes in LOGGDP. This reflects that this explanatory variable is indeed accounting for much of the changes in output. The 0.0176 *p*-value corresponding to capital shows that changes in the variable are statistically insignificant in explaining changes in output at five percent level of significance. Furthermore, the 0.312653 coefficient has a positive sign and it illustrates a positive relationship between LOGK and LOGGDP, where a unit increase in LOGK would lead to a 31 percent increase in log output and vice-versa. This positive relationship between the two reinforces economic theory by Cobb Douglas which argues that the two (capital and output) are positively related.

Additionally the -2.950522 *t*-statistic corresponding to drought dummy variable is greater than the standard critical value of *t* of |2| thus showing that drought as an explanatory variable is statistically significant in explaining the changes in the dependent variable, output (LOGGDP). In other words, drought is accounting for much of the changes in output. The *p*-value of 0.0162 underpins that this explanatory variable is statistically significant in explaining changes in output at five percent level of significance. The coefficient of D in this instance is -0.049968 and has a negative sign showing a negative relationship between droughts and output.

Conclusions and recommendations

The purpose of this study was to examine if whether there is a link between climate change and agricultural output in South Africa in period 1997-2012. The explained or dependent variable in the study was agricultural output explained by variables rainfall and temperature (climate change indicators), labor in the agriculture sector and capital in the same sector too. These explanatory variables carried coefficient signs that confirmed to economic theory except for labor.

Several policy implications arise when looking at the results presented by the study. Policy makers may need to consent with the fact that climate impact on agriculture is real despite the fact that farmers are doing their best to adapt to it. Policies may therefore be needed, and they should be directed at reducing losses by identifying and assessing the efficiency of current coping mechanisms and finding ways to support them.

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