Establishing the nexus between climate change adaptation strategy and smallholder farmers’ food security status in South Africa: A bi-casual effect using instrumental variable approach

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Abstract: Background: Climate change negatively impacted agricultural food production. Amidst the means of adjustment is the use of adaptation strategies to combat the detrimental effect. In order to promote zero hunger, achieve food security and improved nutrition and encourage sustainable agriculture, which were listed under the second goal of the Sustainable Development Goals, then, farmers must necessarily have recourse to controlling measures. Consequently, climate change adaptation strategy was identified as one of the key approaches to achieving the catalogue itemised under the second goal. Hence this study aimed to determine the synergy between climate change adaptation strategy and smallholder farmers’ food security status in South Africa, in addition to exploring factors that influenced the duo. A cross-sectional survey was conducted where 346 maize farmers in Ngaka Modiri Molema District of the North West Province, South Africa were interviewed. Data were analysed using STATA software, while two-stage...

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PUBLIC INTEREST STATEMENT
The primary goal of agriculture is to produce food and sustain a livelihood. However, the agri-food system is threatened by climate change extreme events. Climate change variability poses a major challenge towards food production, thus, adversely affect food security status. There is a need for urgent action to combat this phenomenon and its impact. Climate change adaptation strategy is known to cope in the face of this threat. Hence, this study will be of public interest as it attempts to establish the connection between climate change adaptation strategy and food security status among the smallholder farmers who are most susceptible in the agri-food system. Consequently, the study will be of the public interest as it reveals the food security status in the North West Province of South Africa.
regression model was used to establish the bi-causal link. On the one hand, the result highlighted variables that influenced climate change adaptation strategies: awareness of climate change, access to irrigation and frequency of agricultural extension agent visit. On the other, instrumental variables such as climate change adaptation strategies, household expenditure, and marital status were statistically significant and impact food security status in the study area. The paper established the nexus between climate change adaptation strategy and food security among smallholder maize farmers in the study area. Hence, the study recommended that in order to increase food security status, climate change adaptation strategy must be improved.

Subjects: Statistics for Social Sciences; Sociology; Sociology & Social Policy; Economics; Environmental Economics

Keywords: Climate change adaptation strategies; food security status; instrumental variables

1. Introduction

It is a universal knowledge that climate change is one of the notable threats in the biosphere (Food and Agriculture Organization [FAO], 2018; United Nations Department of Economic and Social Affairs [UNDESA], 2017; United Nations Office for Disaster Risk Reduction [UNISDR], 2015); neither can it be gainsaid that climate change has become a huge peril to agriculture and food security especially in the developing countries where farmers are solely dependent on rainfall, that is, dryland farming. Accordingly, sub-Saharan Africa countries are the most vulnerable to the impact of climate change due to the lack of financial resource to support adaptation strategies (Hallegatte, Vogt-Schilb, Bangalore, & Rozenberg, 2017; World Bank, 2018). For instance, according to Intergovernmental Panel on Climate Change (Intergovernmental Panel on Climate Change [IPCC], 2014), it was reported that Africa is anticipated to lose 0.13–2% of its GDP by 2100 as a result of the negative consequence of climate change in agriculture. Equally, Oduniyi (2018) affirmed that climate change has a negative impact over the years with a drastic reduction in production yield and area of maize farming in South Africa. Over the last few years, agricultural production has been experiencing a major shift in the area of cultivated farmland and production of crops, especially grains. The areas where grains especially maize are planted have declined significantly.

Consequently, the impact of climate change on agricultural production found expression on food security. Meantime, the Food and Agriculture Organisation of the United Nations distinctly noted that food security consisted of 4 pillars (Food and Agriculture Organization [FAO], 2006). Thus, the organization considered food security as the availability of sufficient amount of correct quality of food that is supplied through domestic production (food availability); secondly, the body submitted that an individual’s access to sufficient resources in order to acquire appropriate foods for a nutritious diet was a notation of food accessibility; thirdly, the utilisation of food through adequate diverse diet, clean water, sanitation and health care to reach a state of nutritional well-being where all the needs of physiology are met evidenced food utilisation; and lastly, when individuals or household members have access to sufficient food at all times is a signification of food stability. However, the impact of climate change has worsened the food security status amidst various food security pillars in most developing countries; hence the need to adopt climate change adaptation strategies so as to stem or abate the adverse impact of climate fluctuation on food security.

To that end, climate change adaptation strategies are the prime actions of sorting out or effectual handling of the impacts of climate change. Given this, adaptation strategies are targeted at improving farm productivity despite the inevitability of climate change in order to enhance livelihood and promote food security. However, in sub-Africa, some smallholder farmers trivialise climate change
adaptation strategies since it is costly. For instance, Ncube et al. (2016) confirmed that in South Africa, rural households are generally poor and lack resources to adapt and mitigate the impact of climate change. Consequent upon that, it was noted that small scale maize farmers adjust by reducing the area of cultivated farmland even by half (Oduniyi, 2018). This measure was adopted by the farmers in order to decrease the exposure of their crops to climate risks and uncertainty, which in turn will enable these farmers to survive the contrary impact of climate changeability. Consequently, the deliberate reduction reflects on the quantity of the eventual output produced. Therefore, it is apropos for farmers to utilise adaptation strategies that will stem or greatly reduce the detrimental effects associated with climate change (Dickie et al., 2014).

Even though the majority of the smallholder maize farmers in the study area tried different options according to their capacity, to mitigate the contrary effect of climate change on their farm produce, yet they never recorded any significant success, resulting in low food security, which evidenced lack of climate adaptation strategies. It follows that there is a causal relationship between low food security and climate adaptation strategies; hence there is a growing recognition that climate change adaptation and food security are closely interconnected. Mukherjee (2016) reported that whenever there is any disparity in environmental factors such as temperature, rainfall result in the instability of agricultural productivity which unambiguously affects the food security status of the farmers. The researcher elucidated that a rise in rainfall coupled with maximum and mean temperature has an adverse effect and significantly impact on the food security index and the 4F’s of food security (food availability, food accessibility, food utilisation and food stability). Appositely, Niang et al. (2014) affirmed that climate change is expected to have a negative impact on food security; as such individuals will necessarily be underfed (Parry, 2007). Thus, it is patent that food insecurity results from a complex interaction of multiple stressors (socioeconomic and environmental) over long time periods and with sudden shocks (Akrofi, Price, & Struik, 2012).

Moreover, considering the relevance of utilising adaptation strategies, there is a dearth of study conducted in the study area on the link or bi-causal effect of climate change adaption strategies on food security, also in South Africa at large. Furthermore, there is little or no substantial literature on the relationship and the effect of climate change adaptation strategies and food security in North West Province of South Africa, neither has investigation been carried out on the relationship between both. Given these noted gaps in the scholarship of agriculture, this study set out to establish the nexus between climate change adaption strategies and food security in the study area. The relevance of the study is to create awareness regarding the cause and effect relations or association between adaptation strategies and food security amongst the smallholder maize farmers, stakeholders, and the policymakers, and a consequent stability of food security in the study area.

In addition to the aforementioned significance, the research is expected to improve earlier and various adaptation strategies in the study area, besides helping the smallholder maize farmers in the study area to comprehend the factors responsible for climate change adaptation strategies and food security. To this effect, the objective of the study is to explore the synergies between climate change adaptation strategies and food security in the study area.

2. Research hypothesis
Null hypothesis (H₀): There is no synergy between climate change adaptation strategy and food security (Variables are exogenous).

Alternative hypothesis (H₁): There is synergy between climate change adaptation strategy and food security (Variables are not exogenous which means there is endogeneity).

3. Methodology
Study Area: The study was carried out in Ngaka Modiri Molema (NMM) District Municipality of the North West Province. The province is in the north of South Africa; and it shares a border with the Republic of Botswana and the Kalahari Desert to the west, where Gauteng province is found on the
east and the Free State to the south. The district municipality is the capital of the Province which is situated at the centre of the province. The district consists of Mahikeng, Ditsobotla, Ramotshere Moloa, Tswaing, and Ratlou. The area of the district is 28,206 km\(^2\) with a population of 842,699 (Stats, 2011). The main economy is agriculture, and the towns include Lichtenburg, Sannieshof Delareyville, Zeerust, Mahikeng, Coligny, Disaneng, Mmabatho, Biesiesvlei, Groot Marico, Ottosdal, Setlagole, Madibogo, Kraaipan, and Ottoshoop.

### 3.1 Method of data collection

The study area as shown in Figure 1, is known as one of the largest maize producing areas in South Africa. Farming is the primary occupation for most rural households. The area was purposely selected because of the concentration of small-scale maize farmers in the country. The data used in the research were primary and secondary data. Data were collected between 2017 and 2018 by administering a structured questionnaire to respondents in the study area. The questionnaire consisted of logically flowing questions involving demographics characteristics, climate change adaptation strategies, and food security-related issues. The questionnaires were explained to the local extension officers before the survey because they understand the farmers better and can translate the questionnaires into a local language. Face to face interviews and focus group discussion were conducted in each local municipality where each session lasted for 45 minutes.

### 3.2 Population, sampling procedure, and sample size

A total number of 346 questionnaires were administered to the farmers in the district using stratified random sampling technique. The sampling was carried out by grouping the population of the small-scale maize farmers from the five (5) local municipalities in the district into strata, after which a random sample was used to select from each stratum. A specific number of the sample size was selected from each stratum as shown in Table 1.

This was achieved by adopting a quantitative model as presented below:
n = \frac{N}{1 + N(e)^2} \tag{1}

Where \( n \) is the sample size,

\[ N = \text{total population of the farming households in the 5 local municipalities across the district municipality,} \]

\[ e = \text{maximum variability or margin of error (MoE). This is estimated at 5\% (0.05),} \]

\[ 1 = \text{probability of the event occurring,} \]

\[ 346 = \text{number of respondents sampled or sample size.} \]

3.3 Statistical analysis

Descriptive statistics such as percentage, frequency counts, mean values and standard deviation were used to describe farmers’ socioeconomics, farm-based characteristics, household food security status and climate change adaptation strategies. Principal component analysis (PCA) was used to generate an index (climate change adaptation strategies index) which was used to regress against the independent variables, endogenous variables, and instrumental variables. The index represented a fraction of number of adaptation strategies applied out of the total adaptation strategies available. Following this, a two-stage least squares regression was used to analyse the effect of climate change adaptation strategies on food security status in the study area. Two-stage least square regression was considered a suitable model to use in this research because of its ability to estimate a causal effect of the explanatory variable on the dependent variable. It is preferred for its precise evaluative method in this study when the dependent variable’s error terms are correlated with the explanatory variable of interest. In this case, instrumental variables are introduced which are uncorrelated with the error term to estimate the model parameters. These instrumental variables are correlated to the endogenous variables but not with the error term of the model.

Two-Stage Least-Squares Regression model was employed where the dependent variable was regressed against the independent variables (endogenous variables) and instrumental variables. The method was used to handle the model with endogenous explanatory variables in a linear regression framework. It involved running Ordinary Least Square (OLS) two times. In the first stage, two-stage least square (TSLS) found the portions of the endogenous and exogenous variables that can be attributed to the instruments. This stage involved estimating an OLS regression of each variable in the model on the set of instruments. The second stage was a regression of the original equation, with all of the variables replaced by the fitted values from the first-stage regressions. The coefficients of this regression were the TSLS estimates. The predicted values from these regressions replaced the original values of the endogenous variables in the second stage regression model. Instrumental variables used in the regression

| Stratum (Local Municipalities in the District) | Population of small-scale maize farmers | Selected sample size |
|-----------------------------------------------|----------------------------------------|---------------------|
| Tswaing                                       | 200                                    | 132                 |
| Ditsobotla                                    | 150                                    | 109                 |
| Mahikeng                                      | 100                                    | 80                  |
| Ratlou                                        | 15                                     | 15                  |
| Ramotshere Moiloa                            | 10                                     | 10                  |

Source: Author’s computation, 2017.
framework in this study were: household expenditure, household income, climate change adaptation strategies.

Assume we want to estimate the coefficients of the linear model, mathematically written as:

\[ y = \alpha + \beta x + u \]  

(2)

If the observed independent variable \( x \) contains errors of measurement and we wish to estimate the regression coefficient on the “true” value of \( x \), then the ordinary least squares (OLS) estimator is inconsistent. The simplest and most common model relating the true value to the observed value of \( x \) is:

\[ x = T + e \]  

(3)

where \( T \) is the true value, \( e \) the random error of measurement. We write, similarly to equation 2

\[ x_{ji} = T_{ji} + e_{ji} \]  

(4)

where \( x_{ji} \) is the observed value of item \( j \) for individual \( i \), \( T_{ji} \) is the true value of item \( j \) for individual \( i \), and \( e_{ji} \) is the measurement error.

\[ Y_1 = \theta_0 + \theta_1 X_{11} + \ldots + \theta_k X_{k1} + \epsilon_i \]  

(5)

Where \( Y_1 \) is a dependable variable = Climate change adaptation strategies index.

\[ Y_1 = \theta_0 + \theta_1 X_{11} + \theta_2 X_{12} + \theta_3 X_{21} + \theta_4 X_{41} + \theta_5 X_{51} + \theta_6 X_{61} + \epsilon_i \]  

(6)

But some of the variables \( X_{ji} \) are correlated with the error term as shown in the equation 4 above. OLS estimation of this equation will be biased and inconsistent. Suppose that we have a collection of \( q > p \) instruments, \( Z_{1i} \ldots Z_{qi} \). Where variables \( p \) and \( q \) are called endogenous.

The two-stage least squares estimator of \( \theta \) will be as follows:

Regress each \( X_j \) on \( Z \) and save the predicted values, \( \hat{X}_j \). If \( X_j \) is included in \( Z \), we will have

\[ \hat{X}_j = X_j \]  

Estimate \( \beta \) via the OLS estimate of the regression model

\[ Y_1 = \theta_0 + \theta_1 \hat{X}_{11} + \theta_2 \hat{X}_{12} + \theta_3 \hat{X}_{21} + \theta_4 \hat{X}_{41} + \theta_5 \hat{X}_{51} + \theta_6 \hat{X}_{61} + \epsilon_i \]  

(7)

Consequently, Household food security status was determined using household expenditure survey (HES). Table 2 shows the independent variables with the expected signs used in the binary logistics regression. Following Arene and Anyaeji (2010), this was achieved by calculating the per capita food expenditure of the ith household divided by 2/3 mean per capita food expenditure of all households, over a period of a month. The value obtained represents a threshold which was used to construct the household food security index (HFSI). A household expense on food above the threshold or HFSI is regarded as food secure, otherwise or lesser than the threshold is regarded as food insecure.

\[ \text{HFSI} = \frac{\text{per capita food expenditure for the ith household}}{2/3 \text{ mean per capita food expenditure of all household}} \]  

Where HFSI is the household food security index

Mathematically, when:

\[ F_i \geq 1 = \text{the i-th household is food secure} \]

\[ F_i < 1 = \text{the i-th household is food insecure} \]

Hence, any household with a per capita monthly food expenditure above or equal to two-thirds of the mean per capita food expenditure is considered to be food secure, while otherwise is food insecure.
4. Results and discussion

4.1 Descriptive statistics
The summary of statistics of climate change adaptation strategies, food security status, and socioeconomic characteristics were presented in this section, as well as the endogeneity effect of climate change adaptation strategies on food security status in the study area. Table 3 revealed that 94.5 percent adapt to climate change, while it was discovered that majority of the farmers used minimum or low tillage, followed by plant tolerant maize seeds and changing of planting date as adaptation strategies. Below, is Table 4, which depicted a graphic representation of the different adaptation strategies used by the maize farmers.

Table 5 explicitly explained that about 188 (54.3%) of the household heads were food secured. This could possibly be attributed to the fact that many of the household heads were able to buy food items for the households, and perhaps depended on additional income outside farming. This was a plausible reality because most of the household heads equally had other sources of income in the form of wages, old age and children grants. As represented in Table 6, it was shown that the minimum household expenditure per month was R640, with R79.00 per capita food expenditure, while the maximum household expenditure was R2650 with R640.00 per capita expenditure. Also, the minimum household income per month was calculated to be R1850 while the maximum household income was R4100. Likewise, it was ascertained that the minimum household age was 24 years while the maximum age was 78 years. Minimum household size was 1, while 13 was the maximum household size. Few rural households head had a minimum of 2 years of farming experience whereas the maximum farming experience was 38 years.

5. Effect of climate change adaptation strategy on smallholder farmers’ food security status
The result of the Two-stage least square in Table 7 revealed the endogeneity effect or bi-causal effect of climate change adaptation strategy on food security, whereby two result tables were
presented (First-stage regressions and Instrumental variables (2SLS) regression). First stage regression (as shown in equation 3) output in Table 7, evinced that awareness of climate change is positively and statistically significant (p < 0.05) to climate change adaptation strategies.

### Table 4. Distribution of climate change adaptation strategies

| Adaptation Measures                              | Frequency | Percent |
|-------------------------------------------------|-----------|---------|
| 1. Minimum or Low Tillage                       | 129       | 37.3    |
| 2. Crop Diversification                         | 5         | 1.4     |
| 3. Plant Different Crops                        | 15        | 4.3     |
| 4. Plant Tolerant Maize Seeds                   | 17        | 4.9     |
| 5. Change to Drought Tolerance Crops            | 13        | 3.8     |
| 6. Crop Rotation                                | 28        | 8.1     |
| 7. Changing of Planting Date                    | 17        | 4.9     |
| 8. Reduced Cultivated Land                      | 5         | 1.4     |
| 9. Ripping Deeper and Ploughing Every Year      | 14        | 4.0     |
| 10. Prayers                                     | 6         | 1.7     |
| 11. Improved Land Magt                          | 7         | 2.0     |
| 12. Change of Production Practices              | 1         | 0.3     |
| Combination of 2, 3 & 5                          | 38        | 11.0    |
| Combination of 11 & 12                          | 32        | 9.2     |
| None                                            | 19        | 5.5     |
| Total                                           | 346       | 100.0   |

**Source:** Authors Computation (2018).

### Table 5. Distribution of Household Food Security Status (HFSS)

| Food Security Status  | Frequency | Percentage |
|-----------------------|-----------|------------|
| Food Secure           | 188       | 54.3       |
| Food Insecure         | 158       | 45.7       |
| Total                 | 346       | 100        |

**Source:** Authors Computation (2018).

### Table 6. Summary statistics of selected respondents' socio-economic variables

| Socio-economics variables | Minimum  | Maximum  | Mean     | Variance (n) | Standard deviation (n) |
|---------------------------|----------|----------|----------|--------------|------------------------|
| Household expenditure (R) | 640.000  | 2650.000 | 1433.295 | 187,026.965 | 432.466                |
| Per cap food expenditure (R) | 79.000  | 640.000  | 291.055  | 8549.815    | 92.465                 |
| Household income (R)      | 1850.000 | 4100.000 | 2408.905 | 331,681.838 | 575.918                |
| Household head age        | 24.000   | 78.000   | 53.315   | 218.904     | 14.795                 |
| Household size            | 1.000    | 13.000   | 5.630    | 8.464       | 2.909                  |
| Farming experience (years)| 2.000    | 38.000   | 15.962   | 80.493      | 8.972                  |

**Source:** Authors Computation (2018).

Note: R is ZAR Rand.
While on the contrary, access to irrigation and frequency of extension visit had an inverse relationship with climate change adaptation strategies, but statistically significant at p < 0.05 respectively. However, this result negated a-priori expectation, but the reason for this contrast could be attributed to the fact that more access to irrigation facilities decreased adaptation strategies. The decrease occurred because the farmers spent more money to implement the irrigation system and that in turn resulted in a decrease in the farmers’ resources; consequently, they were unable to try other monetary adaptation strategies. Correspondingly, many researchers averred that adaptation strategies were costly due to low resources, lack of economic and technological resources especially in developing countries (Osumanu, Aniah, & Yelfaanibe, 2017). Congruently, this current research affirmed that an increase in the number of extension visits decreased the utilisation of adaptation strategies in the study area. The reason was that information on adaptation strategies was shared more, in farmers to farmers group, farmers association (belonging to farmer membership club). Nevertheless, a regular visitation did not improve knowledge on adaptation strategies in the study area.

Consequently, the instrumental variables (2SLS as shown in equation 4) regression estimates in Table 6 revealed that climate change adaptation strategies were positively related and statistically significant (p < 0.05) to household food security status. This implied that, as adaptation strategies improved, the status of food security among the smallholder farmers increased as well. Farmers were able to adopt more strategies which increased the yield and production, thus enhancing food security. Household expenditure had an inverse relationship with household food security status, and statistically significant at (p < 0.01). The results indicated that an increase in household expenditure eventuated into a decrease in household food security status; the more the expenses on household needs the lesser the probability of a household to attain food security. In the same vein, the marital status of the head of the household was negatively associated with household food security and statistically significant (p < 0.05). This denoted that with other variables constant, household security for married respondents was relatively less than their unmarried counterparts.
counterparts. This result aligned with Sekhampu’s (2013) findings regarding the marital status of the head of the household, which was found to be negatively associated with household food security.

As demonstrated in Table 7, the examination showed that climate change adaptation strategy was positively associated with food security and statistically significant to food security status in the study area. Also, the estimation of the Wu-Hausman F test and Durbin-Wu-Hausman chi-square test affirmed the endogeneity effect of climate change adaptation strategy on smallholders’ food security status with a significant P-value of 0.03070 and 0.02947, respectively. Additionally, if the Hausman test were significant, it meant there was endogeneity, in this case, two-stage least square would be the best, as it well fitted the model. Then we accept the alternative hypothesis, which implies that there is endogeneity effect; and this subsequently establishes that there is a bi-causal link or synergy between climate change adaptation strategies and food security among the smallholder farmers in the study area.

6. Conclusion
The study underscored the nexus between climate change adaptation strategies and food security among smallholder maize farmers in the study area. On the one hand, the study highlighted variables that influenced climate change adaptation strategies: awareness on climate change, access to irrigation and frequency of extension visit. On the other hand, instrumental variables such as climate change adaptation strategies, household expenditure, and marital status were statistically significant and impact food security status in the study area. Hence, the study recommended that in order to increase food security status in the study area, climate change adaptation strategies must be improved.

List of abbreviations

| Abbreviation | Description |
|--------------|-------------|
| FAO          | Food and Agriculture Organization of the United Nations |
| UNDESA       | United Nations Department of Economic and Social Affairs |
| UNISDR       | United Nations International Strategy for Disaster Reduction |
| IPCC         | Intergovernmental Panel on Climate Change |
| GDP          | Gross Domestic Product |
| PCA          | Principal Component Analysis |
| OLS          | Ordinary Least Square |
| TSLs         | Two-stage Least Square |
| HES          | Household Expenditure Survey |
| HFSI         | Household Food Security Index |
| 2SLS         | Instrumental Variables |

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