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Are SACU countries self-sufficient in cereals? A dynamic panel analysis

H. J. Sartorius von Bach and K. M. Kalundu

Faculty of Agriculture and Natural Resources - Agricultural economics, Department of Animal Production, Agribusiness and Economics, University of Namibia, Windhoek, Namibia

ABSTRACT
Most countries within Southern Africa are reliant on cereal imports from South Africa, Zambia, and Zimbabwe. In the Southern African Customs Union (SACU) region, cereal insecure countries are often import-dependent. Changing income levels, pandemics, climatic conditions and the trade environment all create a wedge and put pressure on food self-sufficiency. This paper uses a robust dynamic approach of a five-country panel to investigate the key determinants of cereal self-sufficiency in the SACU region. Long-term and short-term effects of selected variables are tested using a dynamic panel data model. The key long-term drivers for cereal self-sufficiency are identified and the short-term results reveal that land surface and rainfall are statistically most significant at a level of ten percent. The Dumitrescu-Hurlin panel causality test suggests that SACU member states could propose further macroeconomic harmonisation and good governance to stabilise national income to cushion against the possible increased cost of cereal production especially in Lesotho, Eswatini and Namibia. The adoption of climate smart technology to safeguard against rainfall variability and reduce the carbon footprint is important to foster an increase in agricultural productivity. A lack of effective harmonised policies may lead to an acceleration in cereal production insecurity and increased poverty.

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SACU; cereals; self-sufficiency; dynamic panel data analysis; food policy

1. Introduction

Recent experience with the COVID-19 pandemic indicates that there is need to be more resilient when addressing food security. Low-income countries are prone to the severity of a changing food production environment. The assumption that globalisation and trade liberalisation lessen vulnerability among the World's Nations through economic integration has been debated widely. The expectation that trade-liberalisation can reduce inequalities and shortages in developing countries has already been demonstrated (Artuc, Porto, and Rijkers 2000). However, even with some positive effects of globalisation, many challenges still impede Africa's search to achieve food security to wipe out hunger (Dodo 2020). Recent debates point to the cumulative impacts of climate change leading to volatility in food commodity prices and the dependency on imports.

The key drivers for food availability include urbanisation, globalisation, trade controls, consumption patterns, pests, disease outbreaks, adverse climate conditions on food production, land degradation and water scarcity (Kentor 2001; Battersby 2013; Fyles and Madramootoo 2016; Szabo 2016;

CONTACT H. J. Sartorius von Bach svonbach@iway.na Faculty of Agriculture and Natural Resources - Agricultural economics, Department of Animal Production, Agribusiness and Economics, University of Namibia, Private Bag 13188, Neudamm Campus, Windhoek, Namibia

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Mahrous 2019). These drivers are unsually the cause of famine because global food supply still exceeds food demand by 15 percent (Misselhorn et al. 2012; Herforth and Ahmed 2015). This equilibrium imbalance is the result of food availability.

From the cereal production perspective, most countries in Southern Africa are reliant on South Africa, Zambia and Zimbabwe for food supply. On average, in the Southern African Customs Union (SACU) region, South Africa produces about 97.2 percent and consumes only 51.7 percent of cereals. From a policy perspective, the cereal self-sufficiency status and regional integration calls for readiness. SACU was formed in 1910 and is the oldest customs union, comprising five member countries, namely Botswana, Lesotho, Eswatini, Namibia and South Africa.

Similarities and homogeneity of working towards cereal self-sufficiency among SACU countries mean that policies on food production can have a common structure. Economic stability also exists based on common monetary policies (with the exception of the Botswanan currency). One example of heterogeneity, however, is a difference in country size in terms of land surface, the level of infrastructure development, population size, the available arable land for crop production and the level of technological advancement in crop production. In most of these cases, South Africa remains dominant in terms of its advanced agricultural economy.

SACU was originally created to work towards integration of trade with the main focus on trade promotion and revenue management, with a specific vision of equitable and sustainable development. This unintentionally allowed members to contribute towards improved food availability. SACU also strives for policy coherence with common strategies that benefit the welfare of members' citizens. However, regulations introduced after the coronavirus pandemic (COVID-19) highlighted that there is insufficient cereal production to meet the demand in Southern Africa.

The endorsement of international trade or environmental agreements also drives unanimous behaviour and attitudes towards the reduction of poverty, an increase in cereal production, and the equality of resource. Although the structure of each economy is different, the level of development can nevertheless strive to fulfil these goals by different means.

This paper contributes to the current literature by analysing the cereal self-sufficiency nexus. It is also important to note that the existence of cross-sectional dependence has been used in this paper to achieve more robust results.

These cross-sectional dependencies and cross-country differences are used to analyse the drivers of cereal self-sufficiency, accessibility, usage and stability of cereal production. A dynamic panel data approach has been developed to investigate these drivers of cereal food. The results of this analysis have been used to put forward a reformulation of policies to improve cereal production to ensure food self-sufficiency.

The paper is organised into five sections; Section 2 describes the present cereal production in the SACU region; Section 3 briefly discusses the empirical approach and Section 4 the results while Section 5 concludes with policy recommendations.

2. A situational analysis of cereal in SACU

2.1 Cereal production

Production data in SACU show that more cereals are produced than consumed; however, further disaggregation indicates some other features. Figure 1 presents the country-specific, cereal food[1] production and total consumption data. A disproportion of production output was identified, attributed to the crop surface and higher yields obtained in South Africa. This inferred that partial skewness is not only a systematic challenge in Southern Africa, but may also be an opportunity for SACU to play a role in innovation, trade, health, wealth and geopolitical relations. Pletziger (2020) suggested that trade in cereals, depended on proximity, cultural likenesses and trade which can be adjusted to account for improved future food availability. A literature review of these particular aspects has been used to develop the methodology.

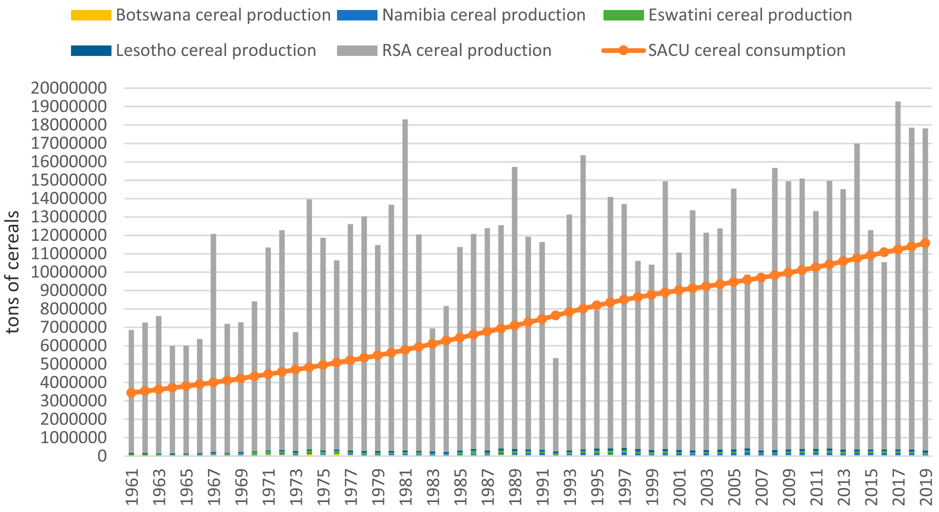

Figure 1. Cereal production and consumption in the SACU region (1961-2019). Source: Taken from the authors own analysis.

Besides the obvious skewness of contributions, climate change also threatens cereal food supply in Southern Africa. Richardson, Lewis, and Krishnamurthy (2018) and Rosegrant et al. (2014) argued that those localities, where there is a higher population density are more vulnerable to the effects of climatic variation. Specifically, the poorer rural communities have limited options to adapt to unexpected climatic conditions. Mora et al. (2015) warned that food producers in underdeveloped regions often experience a decline in crop production. The reasons given for a decline in crop production are often a result of changes in temperature and precipitation. Pugh, Müller, and Elliott (2016) suggested that weather predictions should always be used as a guide when growing crops. Without an optimised approach, the unpredictable effect of climate change on cereal production will often cause an impact on the long-term producer's response (Epule, Ford, and Lwasa 2018). In theory, the volatility caused by climate change will cause uncertainty, which in turn results in a risk-averse crop producer lowering their crop output (De Pinto, Smith, and Robertson 2019).

From the cereal yield per hectare perspective, Figure 2 compares the five-country data. It is deduced that some technological change is present in two countries, while the other countries have not yet responded to technological developmental programmes (Lipton 2012). Over time, South Africa and Namibia have improved their total cereal yield per hectare, while the other countries still average similar yields to those that were achieved decades ago. Tolhurst and Ker

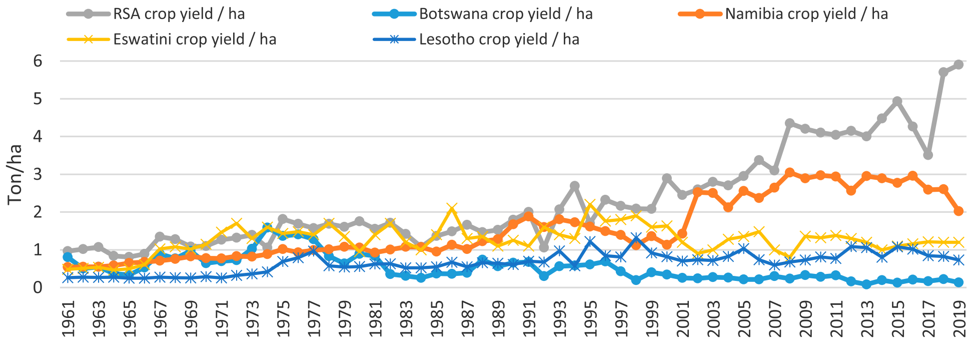

Figure 2. Country cereal crop yield per hectare in the SACU region (1961-2019). Source: Taken from the authors own analysis.

(2015, 137) showed that “technological changes in crop production are relevant to addressing some issues such as food sustainability, economic development, feeding a rapidly growing world population, the effect of new biofuels markets and policies, and climate change”. Therefore, crop development and the diversification of cereal seed supply can have an impact on crop-specific characteristics, but unfortunately this data may be skewed when taking account of aggregation.

2.2 Environmental and other factors

Adams et al. (1999) suggested that climate is often an overlooked factor when considering the impact on crop production. Although precipitation has an obvious influence on crop production, it is important to also consider temperature, wind, and weather patterns. A study by Akpalu, Hassan, and Ringler (2009) determined that a mean temperature increase from 21.4–21.6 degrees Celsius resulted in average maize yield increases of 0.4 percent. In contrast, Zhaoa et al. (2017) showed that for the *ceteris paribus*, each degree-Celsius increase in global mean daily temperature would, on average, reduce the yield of wheat by 6.0 percent, and maize by 7.4 percent. Using long-term general trends, it is important to understand that crop yields depend on the weather effects and the magnitude of climate change. Conradie, Piesse, and Stephens (2019) found that temperature will become the lead determinant for crop production, calling for the more detailed data and the disaggregation of different climatic determinants.

Adverse effects of effective precipitation have a direct impact on crop yield. Akpalu, Hassan, and Ringler (2009) determined that precipitation is the most important crop production driver in South Africa. For maize, a 10 percent reduction in mean precipitation reduces the average yield by 4 percent. Further production volatility can be caused by weather effects, particularly cyclical patterns.

Interestingly, Mulatu, Eshete, and Gatiso (2016) found that non-climatic factors are the main drivers of crop yields in most of Sub-Saharan Africa. Soil is regarded as the major source of crop nutrients which play an important role in crop production. Caiafa and Wrabel (2019) pointed out that agriculture is declining and that farmers’ liabilities are rising, whilst costs are increasing but productivity is in decline. Pressure on the availability of land is common in all SADU countries. Declining available cropland for farmers requires policies to be set that foster long-term productive agriculture (IUCN 2013).

All SACU countries have been increasingly urbanized, which leads to the assumption that CO_2 emissions cannot be separated from their impact on environmental degradation (Li et al. 2018). Salahuddin et al. (2019) examined this link further and found that Sub-Saharan Africa is not yet ready to move towards improving the environment. The long-term CO_2 emission trends for all SACU countries are growing rapidly (Ayompe, Davis, and Egoh 2021). This has a harmful impact on the ecosystem and indirectly affects cereal production too.

Another negative factor is that a third of food produced is wasted globally within the complete supply chain according to EIT Food (2021) estimates. This implies that a significant cropland area used to produce cereals could be better allocated. Mulatu, Eshete, and Gatiso (2016) concluded that CO_2 emissions negatively affected agricultural productivity and household welfare. Within the next two decades, it could lower the real agricultural GDP by as much as 4.5 percent.

2.3 Cereal availability

A literature review suggests that the demand for cereals increases due to a reduction in crop yield and the effects of climate change. Further impact may result from a change to different production systems. For example, Jones and Thornton (2009) identified a switch from crops to livestock production, affecting farm incomes (Kurukulasuriya et al. 2006) and an increased risk of famine and health implications affecting livestock (Speranza, Kiteme, and Wiesmann 2008; López-Carr et al. 2014).

Kotir (2011) argues that the dependence on agricultural production to generate a family income calls for measures to adapt to a likely increase in climatic volatility. It requires climate-smart agriculture, disaster risk reduction and an introduction of improved crop varieties and other agronomic measures (McIntosh et al. 2007; Sain et al. 2017). In addition, there will need to be a better understanding of weather interdependencies as applied to crop production risk discount measures (Arshed and Abduqayumov 2016).

History points to an assumption that enough cereal production ensures adequate availability of staple foods in the marketplace and at household level. However, the focus should not be on production only but should include cereal intake, health, economic, social, and ecological access to food for every human being (Swaminathan 2002). In this paper, the gap between cereal production and consumption by country is defined as cereal food self-sufficiency (see Figure 3).

Figure 3 confirms that South Africa is the dominant player in SACU when it comes to cereal self-sufficiency. Other member states are cereal insecure and rely on imports from South Africa. Therefore, cereal vulnerability often occurs in SACU.

This paper therefore seeks to understand the dynamics of cereal food production and to identify the causes that contribute towards volatility in food availability. With this understanding, it may be possible to formulate improved practices to manage and adapt to any future volatility. Several examples exist. Tandzi and Mutengwa (2020) defined three categories to consider including technological (agricultural practices, management, input availability and markets), biological (diseases, insects, pests and weeds), and environmental (climatic conditions, soil fertility, topography and water quality). These categories are all relevant in the SACU region although they need to be treated differently in each state.

Botswana has the highest urbanisation rate and a strong economy which leads to a high GDP per capita. World Bank data (2020) indicates that Botswana has a population growth of 0.8 percent per annum with an expectation that the cereal dependency level will be maintained for around 900,000 people according to the FAO (2019). On the other hand, Eswatini has the smallest population with about 1 million people. USDA (2021) projects that Eswatini's economy will grow significantly to reach the highest SACU GDP per capita in 2031. This will result in a significant gain in their cereal security. Namibia's urbanisation rate has now reached about 50 percent. With a steady population growth of 1.8 percent per annum (NSA 2020), the GDP will remain relatively low. Cereal production trends are projected to result in a decline in real domestic prices for cereals by 0.6 percent per annum (USDA 2021). This will result in a reduction in the Namibian cereal insecure population from 1.2 million to 800,000 by 2031.

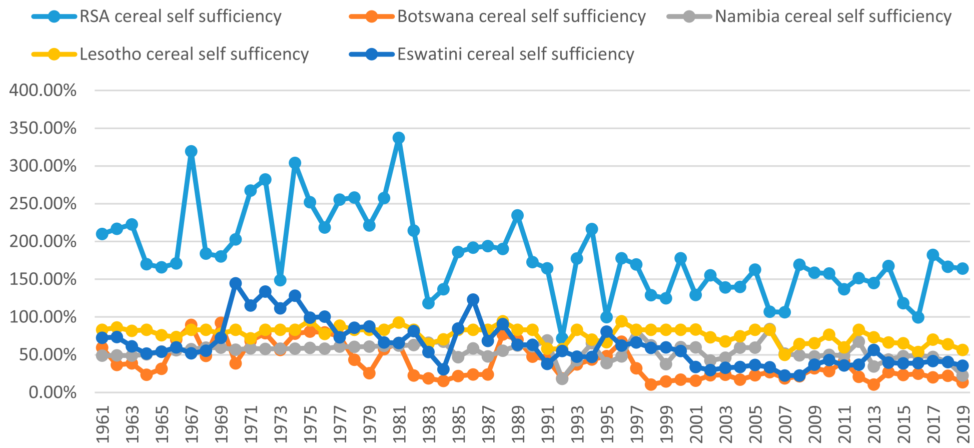

Figure 3. Cereal self-sufficiency in the SACU region (1961-2019). Source: Taken from the authors own analysis.

Lesotho has a smaller economy by GDP per capita and the second smallest population in SACU, which USDA (2021) projects will decline. It might result in a declining cereal dependency, i.e., Lesotho may become the least food insecure country in SACU. South Africa, which is classified as an upper-middle-income country, is the only SACU member state with a low cereal dependency. FAO (2019) estimates a cereal dependency of 16.6 million citizens in South Africa. This amounts to approximately 28.4 percent of the population, which is a significant number.

Based on these projections, it is evident that production, climate, environment and socio-economics will determine regional food self-sufficiency in the SACU region. Further analysis is required to allow policy recommendations to be considered to move towards a regional integration of cereal food self-sufficiency and socio-economic development by the SACU member states.

3. Methodology

3.1 Data selection and description

A balanced panel dataset for the period 1961–2019 was analysed for Botswana, Eswatini, Lesotho, Namibia and South Africa, to produce a balanced stacked panel of 290 observations (T = 58 and N = 5). The choice of the study period was influenced by the availability data, particularly post-independence. A dummy variable was introduced to account for the state independence, to depict the time when SACU member countries entered into new negotiations following the introduction of a new SACU agreement in 2002. This agreement addresses the issues of improving equality of participation, a new revenue-sharing formula and the need to improve integration, without jeopardising the smaller economies and to promote food security.

Production, climate, environmental and socio-economic data were used to determine regional food self-sufficiency in the SACU member states. The transformation of variables into a natural logarithm is ideal to minimise heteroscedasticity; therefore, most of these variables except for temperature were log transformed, while other variables were applied as percentages. Table 1 summarises the dataset used in the analysis.

Table 2 presents a statistical summary of the selected variables. It shows that population has a very significant coefficient of variation and rainfall and crop surface both have a much smaller coefficient. All other variables have been grouped together with a similar, medium coefficient of variation. The overall coefficient of variation shows that the sample period (T) of 58 is large enough for the findings to be considered to be reliable.

3.2 Mean group and dynamic fixed effects modelling

The methodology applied second-generation panel econometric techniques to determine various effects with the variables. First, the analysis evaluated the cross-section dependence of data by determining the best fit and comparing the mean group (MG) with the dynamic fixed effects (PMG). The MG value (see Pesaran and Smith 1995) relies on estimating N time-series regressions and averaging the coefficients, whereas the PMG value (see Pesaran, Shin, and Smith 1999) relies on a combination of pooling and averaging coefficients. It is assumed that the general autoregressive distributed lag (ARDL) can be represented as follows:

$$y_{it} = \sum_{i=1}^{p} \emptyset_{ij} y_{i,t-1} + \sum_{j=0}^{q} \beta'_{i,j} X_{i,t-j} + \mu_t + \epsilon_{i,t}, \tag{1}$$

where X_t are the k-dimensional I (0) exogenous variables that are not co-integrated with the other variables, μ_t is a group specific effect and $\epsilon_{i,t}$ are serially uncorrelated disturbance with zero means and constant variance-covariance. $\beta'_{i,j}$ are $k \times k$ coefficient matrices such that the vector

Table 1. Variable descriptions and sources.

Variable	Code	Definition	Source
Self-sufficiency in cereal production	SESC	Percentage of country cereal production quantity divided by country cereal consumption quantity (%)	https://data.worldbank.org/, https://www.google.com/
Population	LPOP	Total country population (Million)	https://data.worldbank.org/, https://www.google.com/
National income	LNINC	Natural log of national income per capita adjusted from Euros to local currencies	https://wid.world/data
National carbon footprint	LCFPR	Natural log of total country carbon footprint in metric tons of CO_2 emission (2020) [beta]	https://wid.world/data
Southern Oscillation Average Index A	SOAI	Indication of the development and intensity of El Niño or La Niña events in the Pacific Ocean	https://www.ncdc.noaa.gov
Rainfall	LRAIN	Natural log of annual average rainfall (mm) for each member state	https://www.weathersa.co.za/, https://tradingeconomics.com/, https://www.worldweatheronline.com/, https://www.weatherscape.media/
Temperature	TEMP	Average monthly temperature aggregated to an annual state average in degrees C	https://tradingeconomics.com/, https://www.climate.gov/, https://climateknowledgeportal.worldbank.org/, https://library.noaa.gov/, https://www.timeanddate.com/, https://tradingeconomics.com/
Crop surface	LSURF	Natural log of crop surface under cereal production for each member state	https://wid.world/data, https://data.worldbank.org/
Production yield	LYIELD	Natural log of aggregated cereal crop yield in tons/ha for each member state	https://data.worldbank.org/
Independence	IND	A dummy variable used to show the effect on member state independency	https://wid.world/data

Source: Compiled by the authors, 2021.

autoregressive process in $X_{i,t}$ is stable. $\varnothing_{ij}$ are scalars, $t = \max\,(p, q), \ldots, T$, for simplicity assuming that the lag order q is the same for all variables in the $K \times 1$ vector x_t.

If the variables in Equation (1) are co-integrated of the order one ($I(1)$), then the error-correcting speed of adjustment to the long-term equilibrium should be estimated by a dynamic derivation of Equation (1) such that:

$$\Delta y_{it} = \gamma_i (y_{i,t-1} - \theta_i\, X_{it}) + \sum_{j=1}^{p-1} \varnothing_{ij}^{*} \Delta y_{i,t-1} + \sum_{j=0}^{q-1} \beta_{ij}^{*} \Delta X_{i,t-j} + \mu_i + \epsilon_i \tag{2}$$

Table 2. Statistical summary of the variable values.

Variable (name and code)	Mean	Std. dev.	Min.	Max.
Self-sufficiency in cereal production (SESC)	82.98%	59.48%	337.29%	10.58%
Population (LPOP)	8.47	15.35	0.34	58.56
National income (LNINC)	11.61	3.69	5.75	20.44
National carbon footprint (LCFPR)	2.58	1.69	0.35	6.04
Southern Oscillation Average Index (SOAI)	0.97	0.35	0.35	1.68
Rainfall (LRAIN)	6.16	0.39	4.36	7.31
Temperature (TEMP)	19.01	2.68	13.90	24.66
Crop surface used (LSURF)	12.39	1.97	10.34	16.66
Yield per hectare (YIELD)	1.24	0.99	0.06	5.90
Independency (IND)	0.74	0.44	0.00	1.00

where:

$$\gamma_i = \left(1 - \sum_{j=1}^{p} \text{Ø}_{ij}^{*}\right), \quad \theta_i = \sum_{j=0}^{q} \frac{\beta_{ij}^{\prime *}}{(1 - \sum_k \theta_{ik})}, \quad \text{Ø}_{ij}^{*} = -, \quad j = 1,\ 2,\ \ldots,\ P-1 \text{ and}$$

$$\beta_{ij}^{*} = - \sum_{m=j+1}^{q} \beta_{im}, \quad j = 1,\ 2,\ \ldots,\ q-1$$

where γ_i is the error-correcting speed of adjustment term. If $\gamma_i = 0$, then there would be no evidence of a long-term relationship.

A panel model developed in this paper takes into account the autoregressive re-parameterisation in Equations (1) and (2), with self-sufficiency in cereal production (SESC), States (IND), Southern Oscillation Average Index (SOAI), Member state rainfall (LRAIN), temperature (TEMP) and population (LPOP), cereal yield (LYIELD), individual member state carbon footprint (LCFPR), crop surface under cereal production (LSURF), national income (LNINC). The model is represented as follows:

$$\begin{aligned} SESC_{it} = {} & \sum_{i=1}^{P_{IND}} \beta_{it} IND_{it} + \sum_{i=1}^{P_{SOAI}} \beta_{2i} SOAI_{it} + \sum_{i=1}^{P_{RAIN}} \beta_{3i} LRAIN + \sum_{i=1}^{P_{TEMP}} \beta_{4i} TEMP_{it} + \sum_{i=1}^{P_{POP}} \beta_{5i} LPOP_{it} + \sum_{i=1}^{P_{YILD}} \beta_{6i} LYIELD_{it} \\ & + \sum_{i=1}^{P_{CFPR}} \beta_{7i} LCFPR + \sum_{i=1}^{P_{SURF}} \beta_{8i} LSURF_{it} + \sum_{i=1}^{P_{NINC}} \beta_{9i} LNINC_{it} + \sum_{i=1}^{Q_{t-1}} \gamma_i SESC_{it-1} + \text{Ø}_{ij} + \varepsilon_{it} \end{aligned} \tag{3}$$

where, subscripts *i* represent cross-sections ($i = 1, 2, \ldots 5$) and *t* represents the time period (1961–2019). *It* is a group-specific effect for state-specific effects and represent a stochastic error term.

The mean group (MG) parameters are the unweighted means of the individual coefficients, such that the MG estimate of the error correction assumes the following generic representation:

$$\Delta(y_i)_t = \sum_{j=1}^{p-1} \text{Ø}_j^i \Delta(y_i)_{t-1} + \sum_{j=0}^{q-1} \varphi^i \Delta(X_i)_{t-1} + \theta^i[(y_t)_{t-1} - \delta_1^i (X_i)_{t-1}] + \varepsilon_{it} \tag{4}$$

where Ø_j^i, φ^i, θ^i, and δ_1^i are parameters to be estimated and represent short-term coefficients. The error correction term (ECT) and the long-term coefficient also need to be estimated.

It is expected that ECT will be negative if the variables exhibit a return to long-term equilibrium. A pairwise Dumitrescu and Hurlin (2012) panel causality tests is adopted in this study such that:

$$y_{it} = \alpha_i + \sum_{i=1}^{p} \text{Ø}_{ij} y_{i,t-\mathrm{p}} + \sum_{j=0}^{q} \beta_{i,j}^{\prime} X_{i,t-p} + \epsilon_{i,t}, \tag{5}$$

where Ø_j^i, and β_1^i capture the causal relationship in the heterogeneous panel which the pooled mean group (pmg) and mean group are unable to be accounted for in the model.

4. Results and discussion

4.1 Cross-section dependence

Baltagi (2009) suggests that cross-sectional dependence is a problem in macro panels with long time series (over 20–30 years). This is not so much of a problem in micro panels (few years and the large number of cases). The null hypothesis in the Breusch–Pagan/Lagrange Multiplier (B-P-LM) test of independence is that residuals across entities are uncorrelated. The findings from Table 3 illustrate that the null of "no cross-sectional dependence" is rejected at a 10 percent level of significance. Thus, it has been necessary to proceed with tests and estimation techniques that take account of cross-sectional dependence.

Table 3. Summary results for cross-sectional dependence.

Variables	Breusch-Pagan LM	Pesaran scaled LM	Pesaran CD
SESC	118.6342*	24.2913*	10.2414*
INDP	28.5718*	4.1528*	2.9886*
SOAI	590.000*	129.6919*	24.2899*
TEMP	165.8805*	34.8559*	9.2358*
LRAIN	28.5718*	4.1528*	2.9886*
POP	568.7332*	124.9365*	23.84449*
LCFPR	551.7994*	121.1500*	23.4854*
LSURF	188.4406*	39.9005*	1.1841
LNINC	563.7906*	123.8313*	23.7393*

Note: * 10 percent level.

4.2 Pooled mean group long-term and short-term coefficients

The dynamic panel data model for the SACU cross-country analysis allows for testing the long-and short-term effects of the selected parameters. It is evident from the model results, that population, governance (independence), rainfall, the land surface under cereal production, national income and yield are statistically significantly different from zero (refer to Table 4 below). It means that these variables have a significant impact on the long-term self-sufficiency of cereal production between 5 and 10 percent, respectively. For example, an increase in population by 10 percent decreases the ability for individual member state's cereal self-sufficiency by 6 percent. Increased cereal yield per hectare increases the cereal self-sufficiency by 41.6 percent. Also, rainfall and the land surface will increase self-sufficiency in cereal production by 23.4 and 18.4 percent in the long run, respectively.

In the short run, land surface and rainfall are statistically significant at 10 percent. An increase in the cropland surface will increase cereal sufficiency by 64.0 percent, while an increase in rainfall will lead to a 7.4 percent increase in cereal self-sufficiency at member state level.

Table 4 reports the co-integrating equation, which is negative (−0.4929) and significant (probability = 0.0012). This significant result implies that the variables converge to a long-term equilibrium at a speed of convergence of 49.3 percent. Also, the model results indicate that without considering all the variables, member states will be less self-sufficient in cereal production by 1.090 units. Therefore, to minimise the impact of this situation, proper planning and dedication by policymakers and development planners at SACU level is required. It also calls for dynamic effects to be determined.

Table 4. Pooled mean group long-term and short-term coefficients.

Variable	Coefficient	Robust Std. Error	Prob.
POP	−0.0665	0.0095	0.0000*
SOAI	0.0390	0.0506	0.4416
INDP	0.1485	0.0551	0.0076*
LCFPR	−0.1673	0.1305	0.2011
LRAIN	0.2344	0.0676	0.0006**
LSURF	0.1842	0.0530	0.0006**
TEMP	0.0196	0.0226	0.3868
LNINC	−0.0477	0.0280	0.0903*
YIELD	0.4164	0.0758	0.0000**
COINTEQ01	−0.4929	0.1502	0.0012**
D(POP)	−0.0545	0.3890	0.8887
D(SOAI)	−0.0308	0.0329	0.3502
D(INDP)	−0.0503	0.0436	0.2501
D(LCFPR)	0.2065	0.4635	0.6563
D(LRAIN)	0.0738	0.0435	0.0914*
D(LSURF)	0.6404	0.3355	0.0575*
D(TEMP)	−0.0291	0.0352	0.4091
D(LNINC)	−0.1683	0.1451	0.2471
D(YIELD)	0.0289	0.0545	0.5960
Constant	−1.0909	0.4269	0.0113**

Note: *, ** and *** denotes significant at 10, 5 and 1per cent levels, respectively.

4.3 Dynamic fixed effect model results

The endogenous estimators were lagged, with the coefficients of the exogenous variables assumed to be normally distributed. Table 5 shows that population, the Southern Oscillation Average Index (SOAI) and national income are statistically significantly different from zero. These variables have a substantial impact on the long-term self-sufficiency of cereal production at 5 and 10 percent, respectively. An increase in population decreases the ability for a country's cereal self-sufficiency by 0.035 units. Also, an increase in SOAI will increase the self-sufficiency in cereal production by 0.134 units in the long run in the SACU region. The national income uncertainties decrease cereal self-sufficiency by 0.093 units.

In the short term, population, rainfall, the land surface under cereal production, temperature and yield are statistically significant at 5 and 10 percent, respectively. It implies that an increase in the cereal cropland will improve cereal sufficiency by 0.368 units. Increases in rainfall and yield will lead to a 0.245 unit increase in cereal self-sufficiency at member state level.

Table 5 reports the co-integrating equation, which is negative (−0.7565) and significant. This result implies that the variables converge to the long-term equilibrium at a speed of convergence of 75.6 percent. This model suggests that without considering all the variables, member states will be less self-sufficient in cereal production by 1.1613 units.

Various drivers thus explain the cost of achieving a sufficient cereal supply. The higher the temperature and the global SOAI measurement, so cereal production will decrease, and hence signals an increased cost in cereal availability. The model shows that as the SACU population grows, demand for more cereals should be either produced or imported; and this will create a higher cost for member states. Another point on availability is that when the national income increases equitably, Citizens budgets will increase because of the income effect. In the short run, this has the likelihood of increasing cereal consumption, which in the long run may increase cereal cost.

Liu and Ker (2018) showed that the estimation effects of technological changes may result in higher yields than expected. This could be the reason why crop yield and crop surfaces do not provide the expected significance within these models.

Table 5. Dynamics fixed effect results.

Variables	Coefficients	Std. Error	*z*-values
Long-term coefficients			
POP(−1)	−0.0354	0.0116	−3.0500**
SOAI(−1)	0.1342	0.7921	1.6900*
INDEP(−1)	0.0778	0.1212	0.6400
LCFPR(−1)	0.0640	0.1673	0.3800
LRAIN(−1)	0.1499	0.0720	2.0800**
LSURF(−1)	0.1370	0.0689	1.9900**
TEMP(−1)	0.0273	0.0188	1.4500
LNINC(−1)	−0.0933	0.02475	−3.7700**
YIELD(−1)	0.1283	0.0967	1.3300
Short-term coefficients			
ΔPOP	0.4199	0.2235	1.880 0*
ΔSOAI	0.0313	0.0314	1.0000
ΔINDEP	−0.0211	0.0399	−0.5970
ΔLCFPR	0.2865	0.2647	1.0800
ΔLRAIN	0.1340	0.0372	3.6000**
ΔLSURF	0.3686	0.0950	3.8800**
ΔTEMP	−0.0348	0.0178	−1.9600**
ΔLNINC	−0.1509	0.1108	−1.3600
ΔYIELD	0.2456	0.0973	2.5200**
Constant	−1.1613	0.9845	−1.1800
ECT	−0.7565	0.1470	−5.1400**

Note: *, ** and *** denotes significant at 10, 5 and 1 percent levels, respectively.

4.4 Cross-sectional short-term effects

The panel data was disaggregated into individual Member State-specific time series models to discover short term effects. It was assumed that by reducing the number of observations used in the SACU model to individual state models this would reduce the correlation between the mean-differenced regressors and the error term significantly. The Table 6 results show that without considering drivers for cereal self-sufficiency, South Africa is worse off by 13.3, Eswatini by 3.6, Botswana by 3.2 and Namibia by 2.9, while Lesotho is better off by 1.5 units. However, since the size of the member state coefficient for South Africa is large, it signals the importance of the variable for cereal production. This indicates that the drivers for the South African cereal self-sufficiency include rainfall, yield, carbon footprint, the land surface under cereal production and national income. These drivers are statistically significant at 1, 5 and 10 percent. For Lesotho, rainfall and population are major causes influencing cereal self-sufficiency. In Eswatini, governance, yield and the land surface under cereal production are critical factors and these should be addressed to achieve cereal self-sufficiency. For Botswana, governance, rainfall, temperature, population, cereal yields, the land surface under cereal production and national income are significant factors that have an impact on cereal self-sufficiency. For Namibia, the SOAI average index, rainfall, population, carbon footprints level and the land surface under cereal production are critical to achieve self-sufficiency in cereal production.

Some of the variables shown in Table 6 were inconclusive. For example, South Africa shows that for a 10 percent increase in the CO_2 national carbon footprint, the cereal self-sufficiency will decrease by 23 percent. This is a clear sign of how production residues contribute to the increased carbon footprint (see EIT Food 2021). The effect of the carbon footprint on cereal self-sufficiency in Namibia has the opposite effect which shows the significance of emissions resulting from inputs required for cereal production purposes.

The empirical findings from the member state effects match the expectations indicated by USDA (2021). USDA predicts that Lesotho will significantly gain in cereal food security, but Namibia and to a lesser extent South Africa both need to keep focused to improve their cereal food security. Furthermore, provision was made to reduce the observation period starting from 1994.[2]As a result, the dynamic fixed approach has proved to be robust, although the magnitude of some coefficients has changed and thus the size has had an impact on decision-making at member state level. The findings from the dynamic effect shows that the coefficient of rainfall remains positive but has changed to become larger, but temperature has become negative. Furthermore, the coefficient of the aggregated cereal yields is now smaller, and the coefficient for the surface area under production is larger, and the income effect has become smaller. All these changing dynamics have policy implication.

Table 6. Summary of the member state Short-Term effects results.

Variables	South Africa	Lesotho	Eswatini	Botswana	Namibia
INDEP	−0.2748	0.0087	0.2404**	0.1683**	0.0663
SOIA	0.1682	0.0090	0.0863	0.0791	−0.0420*
LRAIN	0.6658***	0.1417**	0.9880	0.2369***	0.09642***
TEMP	−0.0964	−0.0278	0.0374	−0.0960***	−0.01206
LPOP	0.0179	0.2742*	−1.8913	−1.3440***	−0.6121***
LYIELD	0.3579***	−0.1837	0.4284***	0.2222*	−0.0249
LCFPR	−2.3007*	−0.0373	−0.1329	0.2651	0.8145***
LSURF	2.0571***	−0.0773	0.2156**	0.3431***	0.5181***
LNINC	−0.5050**	−0.0579	0.1305	0.1198***	−0.0559
Constant	−13.2982	1.5064	−3.5596**	−3.2037**	−2.9164**
F (9,49)	11.07***	5.32***	23.78***	23.34***	19.74***
R^2	0.6704	0.4943	0.8137	0.81.08	0.7838
Root MSE	0.3467	0.0815	0.1352	0.10.92	0.0581

Note: *, **, *** denotes significance at 10, 5 and at 1 percent levels, respectively.

4.5 Granger causality

This paper has addressed the Granger causality by applying the Dumitrescu-Hurlin panel causality test. The results are presented in Annex 1, which shows that at both 5 and 10 percent levels of significance, the probability values are too large to justify the presence of a causal relationship between self-sufficiency in cereal production and explanatory variables. This indicates the evidence that regional food policy for self-sufficiency is valid within the SACU region. From the Dumitrescu-Hurlin panel causality test, it is evident that future policies need to focus on some variables, such as the allocation of high-value cropland for cereal production rather than for urban settlements. Other significant causalities were also identified and will be discussed in the conclusions below.

5. Conclusions

The similarities and homogeneity across the SACU member states in the cereal self-sufficiency nexus has been examined in detail in this paper. Each individual state's economy structure and level of development level was considered with the prime objective to review their future policy goals. Nevertheless, further research is required to focus on the disaggregation of cereal production and consumption data to improve the economic integration of food self-sufficiency particularly under the COVID-19 pandemic.

The analysis shows that cereal self-sufficiency in the SACU region can be explained considering the following parameters, namely rainfall, population, crop surface, crop yield, and national income and the carbon footprint. Cross-sectional dependence is unlikely because all the variables have a 10 percent significance, except for the surface area under cereal cultivation and the carbon footprint.

The main contribution of this study is to provide a methodology that allows for testing the long- and short-term effects of the selected parameters. The long-term parameters were identified as population, governance, rainfall, the land surface under cereal production, national income and yield, each of which were significantly different from zero. These have a significant impact in the long term on the self-sufficiency of cereal production in the SACU region.

In the short term, only land surface and rainfall are statistically significant at 10 percent. The calculated elasticities allow proper planning and commitment by policymakers and development planners within the SACU region to develop short- and long- term measures leading to self-sufficiency of cereal production. It also calls for adding further dynamic effects based on the improved availability of data.

The dynamic effect model results indicate that the southern oscillation average index and national income are significant determinants for cereal self-sufficiency. These variables appear to have a major impact on the long-term self-sufficiency of cereal production. The SACU model findings show that the variables converge to a long-term equilibrium, at a speed of convergence of 75.6 percent. Therefore, the findings show that without considering all the variables, member states will be less self-sufficient on cereal production by 1.1613 units. Thus, it is inferred from these findings that the selected drivers to reach a sufficient cereal supply in the SACU region should be integrated into policies to mitigate the impact in the long term. It is also important to note that cereal availability is diminishing as the national income increases equitably. The citizens' budget line increases because of the income effect; in the short term. This has the potential to increase cereal consumption in the short term, but in the long term it may also increase the cereal costs.

The drivers for the member state-specific effects on cereal self-sufficiency differsin each country. At the SACU policy level, the key determinants for cereal self-sufficiency should be addressed using a more harmonised integral reform process based on drought preparedness and stabilisation of national income. The Dumitrescu-Hurlin panel causality test justifies the presence of a causal relationship between self-sufficiency in cereal production and explanatory variables. It is important to focus on the allocation of high-value arable cropland for cereal production, rather than for other development strategies such as urban settlement to address the issue of population growth.

The Dumitrescu-Hurlin panel causality test suggests that SACU member states could propose further macroeconomic harmonisation to stabilise national income and cushion against an increase in cereal production costs. The findings on climatic variables call for the adoption of climate smart technology to safeguard against rainfall variability leading to a reduction in the carbon footprint to foster an increase in agricultural productivity.

SACU member states should double their efforts on good governance, geared towards effective policy implementation to minimise inequality, especially in Lesotho, Eswatini and Namibia, and to monitor impacts such as social unrest, where food self-sufficiency is concerned. Only through effective and harmonised policies can future cereal production be secured.

In conclusion, this paper provides the key evidence-based answers to support a revision of the regional cereal food policy leading to an outcome of cereal self-sufficiency within the SACU region.

Notes

1. Maize, wheat, sorghum and millet.
2. In comparison to the period starting in 1961.

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Annex 1: Dumitrescu-Hurlin panel causality test.

Null Hypothesis:	W-Stat.	Zbar-Stat.	Prob.
POP does not homogeneously cause SELFSUFFIC	8.42870	6.55731	5.E-11
SELFSUFFIC does not homogeneously cause POP	2.87021	0.81617	0.4144
SOIA does not homogeneously cause SELFSUFFIC	2.44018	0.37202	0.7099
SELFSUFFIC does not homogeneously cause SOIA	1.12373	−0.98769	0.3233
INDEP does not homogeneously cause SELFSUFFIC	5.14835	3.16917	0.0015**
SELFSUFFIC does not homogeneously cause INDEP	2.29551	0.22259	0.8239
LCARBFOOT does not homogeneously cause SELFSUFFIC	9.09968	7.25033	4.E-13
SELFSUFFIC does not homogeneously cause LCARBFOOT	0.87323	−1.24642	0.2126
LRAINFALL does not homogeneously cause SELFSUFFIC	3.35500	1.31690	0.1879
SELFSUFFIC does not homogeneously cause LRAINFALL	1.84252	−0.24528	0.8062
LSURFACE does not homogeneously cause SELFSUFFIC	6.79263	4.86748	1.E-06
SELFSUFFIC does not homogeneously cause LSURFACE	14.2729	12.5935	0.0000***
TEMP does not homogeneously cause SELFSUFFIC	5.37839	3.40677	0.0007***
SELFSUFFIC does not homogeneously cause TEMP	2.61547	0.55307	0.5802
LINCOME does not homogeneously cause SELFSUFFIC	9.37196	7.53156	5.E-14
SELFSUFFIC does not homogeneously cause LINCOME	1.38392	−0.71895	0.4722
YIELD does not homogeneously cause SELFSUFFIC	4.46221	2.46048	0.0139**
SELFSUFFIC does not homogeneously cause YIELD	3.62115	1.59179	0.1114
SOIA does not homogeneously cause POP	1.62804	−0.46681	0.6406
POP does not homogeneously cause SOIA	1.99259	−0.09028	0.9281
INDEP does not homogeneously cause POP	8.73144	6.86999	6.E-12
POP does not homogeneously cause INDEP	2.60752	0.54485	0.5859
LCARBFOOT does not homogeneously cause POP	34.2397	33.2164	0.0000***
POP does not homogeneously cause LCARBFOOT	5.80779	3.85028	0.0001***
LRAINFALL does not homogeneously cause POP	1.42071	−0.68095	0.4959
POP does not homogeneously cause LRAINFALL	1.51184	−0.58683	0.5573
LSURFACE does not homogeneously cause POP	3.26768	1.22670	0.2199
POP does not homogeneously cause LSURFACE	11.9214	10.1647	0.0000***
TEMP does not homogeneously cause POP	3.28318	1.24271	0.2140
POP does not homogeneously cause TEMP	2.86530	0.81110	0.4173
LINCOME does not homogeneously cause POP	6.60853	4.67733	3.E-06***
POP does not homogeneously cause LINCOME	7.01213	5.09419	4.E-07***
YIELD does not homogeneously cause POP	2.96118	0.91013	0.3628
POP does not homogeneously cause YIELD	6.50516	4.57056	5.E-06***
INDEP does not homogeneously cause SOIA	1.11348	−0.99828	0.3181
SOIA does not homogeneously cause INDEP	1.93509	−0.14967	0.8810
LCARBFOOT does not homogeneously cause SOIA	1.91690	−0.16845	0.8662
SOIA does not homogeneously cause LCARBFOOT	2.83831	0.78322	0.4335
LRAINFALL does not homogeneously cause SOIA	1.22346	−0.88468	0.3763
SOIA does not homogeneously cause LRAINFALL	4.52216	2.52240	0.0117**
LSURFACE does not homogeneously cause SOIA	3.65909	1.63098	0.1029
SOIA does not homogeneously cause LSURFACE	3.22383	1.18142	0.2374
TEMP does not homogeneously cause SOIA	1.98204	−0.10118	0.9194
SOIA does not homogeneously cause TEMP	11.4279	9.65503	0.0000***
LINCOME does not homogeneously cause SOIA	3.22953	1.18730	0.2351
SOIA does not homogeneously cause LINCOME	1.03391	−1.08047	0.2799
YIELD does not homogeneously cause SOIA	1.22570	−0.88237	0.3776
SOIA does not homogeneously cause YIELD	3.23292	1.19080	0.2337

(*Continued*)

Continued.

Null Hypothesis:	W-Stat.	Zbar-Stat.	Prob.
LCARBFOOT does not homogeneously cause INDEP	1.21048	−0.89809	0.3691
INDEP does not homogeneously cause LCARBFOOT	1.22857	−0.87941	0.3792
LRAINFALL does not homogeneously cause INDEP	2.03832	−0.04305	0.9657
INDEP does not homogeneously cause LRAINFALL	1.57813	−0.51836	0.6042
LSURFACE does not homogeneously cause INDEP	2.38255	0.31249	0.7547
INDEP does not homogeneously cause LSURFACE	3.97218	1.95436	0.0507**
TEMP does not homogeneously cause INDEP	1.11481	−0.99691	0.3188
INDEP does not homogeneously cause TEMP	2.06889	−0.01147	0.9908
LINCOME does not homogeneously cause INDEP	2.32296	0.25095	0.8019
INDEP does not homogeneously cause LINCOME	0.73788	−1.38622	0.1657
YIELD does not homogeneously cause INDEP	1.45285	−0.64775	0.5171
INDEP does not homogeneously cause YIELD	3.01109	0.96168	0.3362
LRAINFALL does not homogeneously cause LCARBFOOT	1.66514	−0.42849	0.6683
LCARBFOOT does not homogeneously cause LRAINFALL	2.26308	0.18910	0.8500
LSURFACE does not homogeneously cause LCARBFOOT	5.13410	3.15446	0.0016**
LCARBFOOT does not homogeneously cause LSURFACE	9.07801	7.22795	5.E-13***
TEMP does not homogeneously cause LCARBFOOT	1.80143	−0.28772	0.7736
LCARBFOOT does not homogeneously cause TEMP	4.32629	2.32010	0.0203**
LINCOME does not homogeneously cause LCARBFOOT	9.55748	7.72318	1.E-14***
LCARBFOOT does not homogeneously cause LINCOME	7.53260	5.63176	2.E-08***
YIELD does not homogeneously cause LCARBFOOT	2.65672	0.59567	0.5514
LCARBFOOT does not homogeneously cause YIELD	6.44018	4.50345	7.E-06***
LSURFACE does not homogeneously cause LRAINFALL	0.99080	−1.12499	0.2606
LRAINFALL does not homogeneously cause LSURFACE	1.93145	−0.15343	0.8781
TEMP does not homogeneously cause LRAINFALL	2.07739	−0.00269	0.9979
LRAINFALL does not homogeneously cause TEMP	1.01045	−1.10469	0.2693
LINCOME does not homogeneously cause LRAINFALL	1.18631	−0.92305	0.3560
LRAINFALL does not homogeneously cause LINCOME	1.79584	−0.29349	0.7691
YIELD does not homogeneously cause LRAINFALL	3.76991	1.74544	0.0809*
LRAINFALL does not homogeneously cause YIELD	6.86806	4.94538	8.E-07***
TEMP does not homogeneously cause LSURFACE	3.54922	1.51749	0.1291
LSURFACE does not homogeneously cause TEMP	2.49006	0.42353	0.6719
LINCOME does not homogeneously cause LSURFACE	9.09573	7.24625	4.E-13***
LSURFACE does not homogeneously cause LINCOME	0.70442	−1.42078	0.1554
YIELD does not homogeneously cause LSURFACE	6.74724	4.82059	1.E-06***
LSURFACE does not homogeneously cause YIELD	2.26012	0.18604	0.8524
LINCOME does not homogeneously cause TEMP	4.43960	2.43713	0.0148**
TEMP does not homogeneously cause LINCOME	2.54264	0.47784	0.6328
YIELD does not homogeneously cause TEMP	3.26027	1.21906	0.2228
TEMP does not homogeneously cause YIELD	2.96264	0.91164	0.3620
YIELD does not homogeneously cause LINCOME	3.09956	1.05306	0.2923
LINCOME does not homogeneously cause YIELD	5.85074	3.89464	0.0001***

Note: *, **, *** denotes significance at 10, 5 and at 1 percent levels, respectively.