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Article

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Dynamic relationship among CO_2 emission, agricultural productivity and food security in Nigeria

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Abstract: The study analyzed the dynamic relationship among CO_2 emission (CE), agricultural productivity (AGP), and food security (FS) in Nigeria. The study used annual time series data spanning from 1961 to 2010. Results based on Augmented Dickey and Fuller and Phillip and Perron tests showed that the series are integrated of order one, I(1). Johansen cointegration test was employed to examine the long run relationship. Results show there is no long run relationship among the three variables. Evidence based on the VAR estimates and the impulse response functions shows that there is a negative and significant short run relationship between CO_2 and AGP and between CO_2 and FS. Also the variance decomposition analyses showed that over time, CE contributed about 23 and 22 percent to the variation in AGP and FS, respectively. Further, analysis based on Granger causality test indicated that there was a unidirectional causality from CE to AGP and also from CE to FS. Policies that will assist in the mitigation of CE including investment in research and development, cap and trade system, carbon tax policy, adoption of clean power plan, and other regulatory measures are recommended.

Subjects: Agriculture & Environmental Sciences; Environment & Agriculture; Environmental Sciences

Keywords: CO_2 emission; agricultural productivity; food security; dynamics

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PUBLIC INTEREST STATEMENT

The world is on a paradigm and Nigeria is not left behind on the burden of the vulgaries of carbon (IV) oxide (CO_2). CO_2 emission (CE) has been known as a noble killer. This is so because, damage from consumption of the toxic emissions by the surrounding vegetation may affect the quality and esthetic value of plants and reduces their economic value among others. CO_2 may worsen the living conditions for many who are already vulnerable, particularly in developing countries because of the lack of assets and adequate insurance coverage. To this end, this research was carried out to examine the dynamic relationship between climate change, food security (FP) and agricultural productivity (AGP) in Nigeria. Our findings show that CE has a negative effect on AGP and FS albeit in the short run. Hence the need to formulate and implement appropriate policies for reduction of CE cannot be overstressed.

1. Introduction

Nigeria has been predicted to be among the twenty most developed economies in the world by 2020. Agriculture has been identified to be the major sector that can bring about this laudable achievement. Nigeria has the ambition of diversifying her economy from crude petroleum dependence hence the National Industrial Revolution Plan of 2011. The once dominant subsistence-oriented farm economy is at risk of gradual marginalization (Federal Ministry of Environment [FME], 2010).

More so, Food and Agriculture Organisation [FAO] (2008) estimates indicated that the number of hungry and malnourished people due to insufficient food availability and lack of access to food, have increased from about 90 million in 1970 to about 225 million in 2008, and is projected to add over 100 million by 2015. This is so because, the Nigeria agriculture which as at the time she gained her political independence in 1960 was the dominant sector of the economy, contributing about 70 percent of the gross domestic product (GDP), employing about the same percentage of the working population, and accounting for about 90 percent of foreign earning and federal government revenue (Central Bank of Nigeria [CBN], 2010), contributing 25 percent to the nation's GDP between 1975 and 1979 and 40 percent as at 2013 (FININTEL, 2014) has nosedived. Between 1970 and 1982, agricultural production stagnated at less than 1percent annual growth rate, while there was a sharp decline in export crop production and food production increased only marginally at a time when the population growth rate was between 2.5 and 3.0 percent per annum (Kasozi, 2014).

The country faces a looming food security (FP) crisis following the Obioh (2003) report on greenhouse gas (GHG) emission. It is estimated that extraction and burning of fossil fuels is the source of about 70–90% of anthropogenic CO_2 emissions (CEs) (Edge & Tovey, 1996; Olivier, Janssens-Maenhout, & Peters, 2013; Strong, 1992) the most important GHG. Greenhouse effect is a natural phenomenon. A natural mix of certain GHGs reside in the atmosphere. They allow the short-wave radiation from the sun to penetrate the atmosphere, but absorb the lower wavelength energy which is re-radiated from the earth's surface (Clayton, 1996; Houghton, 1998). Because these GHGs are good absorbers of heat radiation coming from the earth's surface, they act like a blanket over the earth's surface, keeping it warmer than it otherwise would be.

Enhanced greenhouse effect, on the other hand, is not natural. It refers to the changes in the earth's radiation balance due to the anthropogenic accumulation in the atmosphere of radioactively active GHGs (Abubakar & Apagu, 2011). Damage from consumption of the toxic emissions from CO_2 by the surrounding vegetation can affect the quality and esthetic value of plants and reduce their economic value (Westenbarger & Frisvold, 1994). When CO_2 sinks in the atmosphere (Johnson and Fegley, 2002), the resulting water can become harmful to vegetation (Cape, 2003) and aquatic life (Havens, Yan, & Keller, 1993). In respect of health implications, the acidic reactions mix and travel with the air and can lead to leukemia; CO_2 worsens the living conditions for many who are already vulnerable, particularly in developing countries because of the lack of assets and adequate insurance coverage.

CE may impact on the four key dimensions of FS—availability, stability, access, and utilization (Schmidhuber & Tubiello, 2007). Availability of agricultural products may be affected by CO_2 directly through its impacts on crop yields, crop pests and diseases, and soil fertility and water-holding properties. It can also be affected by climate change indirectly through its impacts on economic growth, income distribution, and agricultural demand (Schmidhuber & Tubiello, 2007). In addition, stability of crop yields and food supplies may be negatively affected by variable weather conditions. Physical, economic, and social access to food would be affected negatively by CO_2 as agricultural production declines, food prices rise, and purchasing power decreases. Moreover, CE poses threats to food utilization through its effect on human health and the spread of diseases in geographical areas which were previously not affected (IPCC, 2011).

Since carbon emission may have implications for fresh water resources, agriculture and food supply, natural ecosystems, biodiversity and human health (Ayres & Walter, 1991; IPCC, 1996, 2007), it is imperative to quantify its impacts. So far some studies (Ater & Aye, 2012; Aye & Ater, 2012; Chang, 2002; Cline, 2008; Deressa, Hassan, & Poonyth, 2005; Fonta, Ichoku, & Urama, 2011; Gbetibouo & Hassan, 2005; Hassan, 2008; Kurukulasuriya & Ajwad, 2003; Maddison, 2000; Mendelsohn & Dinar, 1999; Mendelsohn & Nordhaus, 1996; Mendelsohn, Nordhaus, & Shaw, 1994; Molua, 2002; Sakurai, Song, Tachibana, & Takahashi, 2014; Seo, Mendelsohn, & Munasinghe, 2005) have analyzed the impact of climate change variables such as rainfall, temperature, sea level rise among others on agricultural productivity (AGP) and/or FS. More reviews can be found in Kang, Khan, and Ma (2009).

A few studies have used CO_2 or combination of the GHG emissions as measures of climate change and subsequently examined the impact on agriculture. These include Valin et al. (2013) who investigate the effects of crop yield and livestock feed efficiency scenarios on GHG emissions from agriculture and land use change in developing countries using the global partial equilibrium model and find that closing yield gaps by 50% for crops and 25% for livestock by 2050 would decrease agriculture and land use change emissions by 8% overall, and by 12% per calorie produced. Valin et al. (2013) essentially focused on the reverse effect of AGP on GHG emissions. Using the sum of the three popular GHG emission (CO_2, methane and nitrous oxide emissions) as a proxy for climate change and autoregressive distributed lag (ARDL) model, Ekpenyong and Ogbuagu (2015) found that climate change has a negative effect on AGP and 100% increase in greenhouse emission will lead to 22.26% decline in AGP. In this study, the effect of CE is masked by using the sums of the three GHGs. Further, Dawit, Zerayehu, and Tsegaye (2016) used a computable general equilibrium model to investigate the impact of simulated CEs on agricultural performance and household welfare for the period 2010–2030. Their simulation results indicate that CEs negatively affect agricultural total factor productivity and household welfare. Compared to the baseline, real agricultural GDP was projected to be 4.5% lower in the 2020s under a no-CRGE scenario. Specifically, CEs lead to a decrease in the production of traded and non-traded crops, but not livestock. Emissions also worsen the welfare of all segments of households, where the most vulnerable groups are the rural poor households. Dawit et al. (2016) is based on simulation with a variety of assumptions. However, an empirical study based on quantifiable statistical analysis is needed.

Against this background, this study examines the dynamics relationship among CE, AGP, and FS. Since CO_2 is one of the key drivers of climate change, it is important to analyze its specific dynamic relationship with AGP and FS simultaneously. This is the goal of this study. The specific objectives of the study are to examine the short run relationship among CE, AGP, and FS, the long run relationship among these variables as well as the causal relationship among them. These specific objectives lead us to test the following null hypotheses: the first null hypothesis is that there is no long run relationship among CE, AGP, and FS. The second null hypothesis is that there is no short run relationship among CE, AGP, and FS. The third null hypothesis is that there is no significant causal relationship between CE and AGP in Nigeria. While the fourth null hypothesis is that there is no significant causal relationship between CE and FS in Nigeria.

2. Data and empirical models

Data were collected from secondary sources only. Annual time series data on AGP, FS, and CE were collected. AGP was measured as the gross production index number for agriculture (2004–2006 = 100) calculated by the Laspeyres formula. FS was measured as the gross per capita production index number for food (2004–2006 = 100). This measure belongs to the food availability component of FS. CE was measured as CE in kilotonnes. Data on agriculture productivity and FS were collected from the Food and Agriculture Organisation (FAO). Data on CE was collected from the World Bank. While AGP and FS data spans from 1961 to 2013, the CE data covers from 1961 to 2010. Therefore, the study used data on the three series from 1961 to 2010. The plots of the three series in logs are shown in Figure 1. There appears to be sort of inverse relationship between CE and AGP and CE and FS. However, these will be confirmed from statistical tests.

The econometric tools employed for data analysis were based on the objectives of the study. However, given that the study uses time series, a preliminary analysis of the unit root properties of the variables was analyzed to avoid spurious regression. In order to examine the long run relationship between CE, AGP and FS, the Johansen (1991, 1995) cointegration technique was used. For the short run relationship between CE, AGP and FS, the vector autoregressive (VAR) model was used. To analyze the causal relationship between CO_2 and AGP as well as the causal relationship between CO_2 and FS, the standard Granger causality test was employed.

Assume a vector: X_t and assume that the vector has a VAR representation of the form:

$$X_t = \sum_{i=1}^{p} A_i X_{t-i} + Bz_t + \varepsilon_t \tag{1}$$

where X_t is a vector of non-stationary $I(1)$ variables. For this study X_t includes CE, AGP, and FS. z_t is a $n \times 1$vector of deterministic variables, ε_t is a $n \times 1$ vector of white noise error terms or innovations. In order to use the Johansen test, the VAR above needs to be turned into an ECM specification (Brooks, 2002), which may be specified as:

$$\Delta X_t = \Pi X_{t-1} + \sum_{i=1}^{p-1} \Gamma_i X_{t-i} + Bz_t + \varepsilon_t \tag{2}$$

Where:

$$\Pi = \sum_{i=1}^{p} A_i - I, \ \Gamma = -\sum_{j=i+1}^{p} A_j \tag{3}$$

where X is a vector of 1(1) variables defined above, ΔX_t are all 1(0) variables, Δ indicates the first difference operator, π is an $n \times n$ coefficient matrix whose rank determines the number of cointegrating relationships.

This study also employs the Granger (1969) causality approach for testing the causal relationship between CE and AGP as well as between CE and FS in Nigeria.

The Granger causality test assumes that the information relevant to the prediction of the respective variables, CE, FS, and AGP is contained solely in the historical times series data on these variables. The test involves estimating bivariate regressions. For the causal relationship between CE and AGP, the empirical bivariate regressions are given as:

$$\mathrm{CE}_t = \alpha_0 + \sum_{i=1}^{p} \alpha_i \mathrm{AGP}_{t-i} + \sum_{i=1}^{p} \beta_i \mathrm{CE}_{t-i} + \varepsilon_{1t} \tag{4}$$

$$\mathrm{AGP}_t = \lambda_0 + \sum_{i=1}^{p} \lambda_i \mathrm{AGP}_{t-i} + \sum_{i=1}^{p} \delta_i \mathrm{CE}_{t-i} + \varepsilon_{2t} \tag{5}$$

where CE is carbon emission and AGP is agricultural productivity. The error terms, ε_{1t} and ε_{2t} are assumed to be uncorrelated. α, β, λ, and δ are parameters to be estimated. Equation (4) postulates that current CE is related to past values of itself as well as that of AGP and Equation (5) represents a

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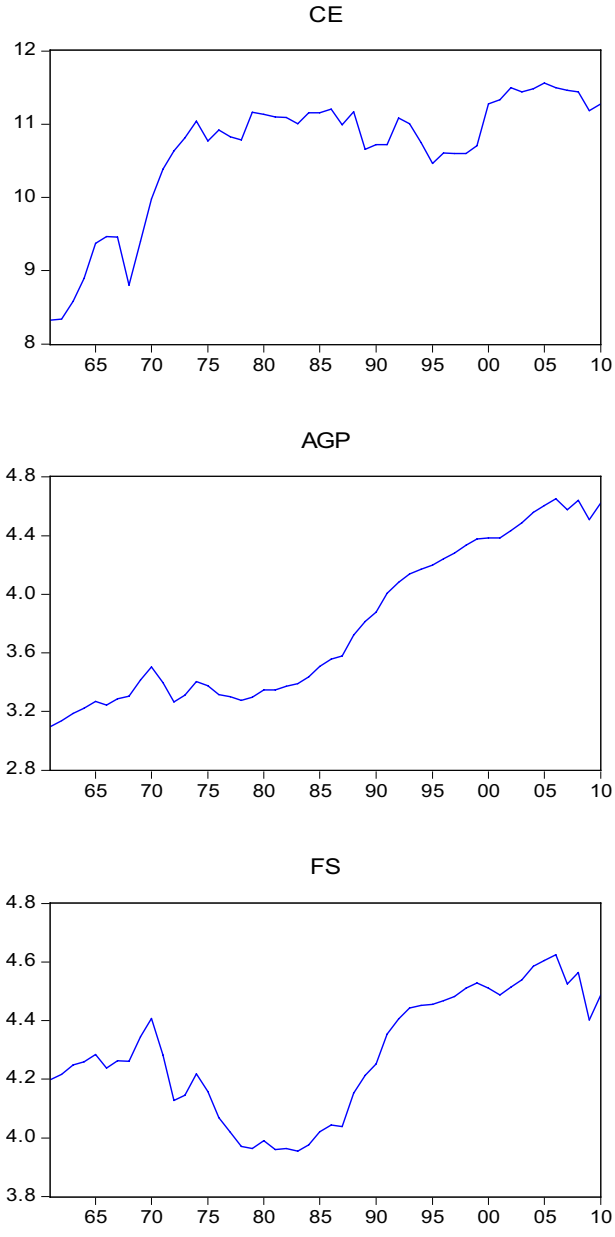
Figure 1. Plot showing CE, AGP, and FS.



similar behavior for AGP. Granger (1969) causality test requires that all variables are stationary, hence we conducted the test using the first differenced series.

For the causal relationship between CE and FS, the empirical bivariate regressions are given as:

$$\mathrm{CE}_t = \gamma_0 + \sum_{i=1}^{p} \gamma_i \mathrm{FS}_{t-i} + \sum_{i=1}^{p} \theta_i \mathrm{CE}_{t-i} + \varepsilon_{3t} \tag{6}$$

$$\mathrm{FS}_t = \omega_0 + \sum_{i=1}^{p} \omega_i \mathrm{FS}_{t-i} + \sum_{i=1}^{p} \phi_i \mathrm{CE}_{t-i} + \varepsilon_{4t} \tag{7}$$

Table 1. Unit root tests

Variables	Level		First difference		Decision
	t-statistic	Probability	*t*-statistic	Probability	
ADF					
AGP	−1.400	0.849	−5.854***	0.000	I(1)
FS	−1.361	0.860	5.819***	0.000	I(1)
CE	−2.238	0.459	−6.614***	0.000	I(1)
PP					
AGP	−1.480	0.823	−5.821***	0.000	I(1)
FS	−1.348	0.863	−5.792***	0.000	I(1)
CE	−2.157	0.502	−6.652***	0.000	I(1)

***Indicates significance at 1 percent level.

where FS is FS, γ, θ, ω, and ϕ are parameters to be estimated and ε_3 and ε_4 are the corresponding error terms for Equations (6) and (7), respectively.

3. Results

3.1. Preliminary analysis

To determine the unit root properties of the data, two commonly used tests are employed namely the Augmented Dickey and Fuller (ADF) and Phillip and Perron (PP) unit root tests. The results of these tests are presented in Table 1. For all the three variables in levels and based on the ADF and PP unit root tests, the null hypothesis of existence of unit root cannot be rejected as evidenced by small *t*-statistic and large *p*-values. This implies that AGP, FS, and CE have unit roots and hence are non-stationary. Based on this, the unit root tests were performed again on the first differences of these variables. The null hypothesis in both ADF and PP tests is rejected at 1% for all the three variables. This implies that the series are stationary in their first difference. Hence, it is concluded that AGP, FS, and CE are integrated of order one, $I(1)$.

3.2. Long run relationship between CE, AGP and FS

The long run relationship between CE, AGP and FS were analyzed based on the Johansen cointegration test. Results from both the trace and maximum Eigen value are presented in Table 2. A VAR of order 2 was estimated based on the Akaike Information Criteria for lag length. The other standard criteria also gave similar result (Appendix 1). The trace test and maximum Eigen values indicate no cointegration at the 5 percent level. Therefore the null hypothesis that there is no long run relationship between CE, AGP and FS cannot be rejected. Therefore, this implies that there is no long run relationship between CE, AGP and FS. This alternatively implies that the variables do not move together over time. Again, it can be said that although the three variables are non-stationary, their linear combination is also non-stationary. The absence of long run relationship also implies that if these variables deviate from the mean or equilibrium level, it will be difficult to bring them back to equilibrium since there is no error correction for the relationship.

Given the projections by IPCC and studies based on simulations, one would expect to see a long run relationship between CE and economic variables. However, the finding of no long run relationship in this study is consistent with the study by Choi, Heshmati, and Cho (2010) who investigated the relationships between CEs, economic growth and openness for China, Korea, and Japan and found evidence of large heterogeneity among the countries and variables impacts. While a long run relationship exists for China and Korea, long run relationship was not found for Japan where as a short run relationship was found for all three economies. In our case we may explain the absence of long run relationship from the point of view of Nigeria's CEs intensity which may not be so huge at

Table 2. Johansen cointegration test based on VAR

Hypothesized No. of cointegrating equations	Statistic	5% Critical value	Probability
Trace test			
None	28.274	29.797	0.074
At most 1	9.691	15.495	0.305
At most 2	0.383	3.841	0.536
Maximum Eigen value test			
None	18.583	21.132	0.110
At most 1	9.308	14.265	0.261
At most 2	0.383	3.841	0.536

the moment to result to a longer term impact. However, if the accumulation is not curbed by necessary policy actions, this may eventually lead to long-term economic damage.

3.3. Short run relationship between CE, AGP and FS

Since the Johansen cointegration test did not detect a long run relationship between CE, AGP and FS, the short run analysis was conducted in a VAR framework. According to Alege (2010), the main strength of the VAR model lies in the fact that it helps to observe impulse response mechanisms, study variance decomposition of variables in the system, for forecasting, causality, and policy analysis (Alege & Osabuohien, 2010). Table 3 shows the VAR estimates. It can be observed that CE has negative and significant effect on AGP and FS at 10 percent level in the first lag and at 5 percent level in the second lag. This implies there is a short run relationship between CE and AGP and between CE and FS.

An impulse response function shows the response of variables to one standard deviation shock in itself and in other variables in the model over a particular time period. According to Alege (2010), impulse response functions trace out how the endogenous variables of the model respond to changes which the economy undergoes within a given period. Simply put, it traces out how the change in one variable impacts other endogenous variables. This study used Cholesky one standard deviation innovation over a time period of ten years. The impulse response functions also show the upper and lower boundary using positive and negative two standard errors.

From the second panel of Figure 1, it is observed that AGP's response to a shock in CE was initially (first period) positive but not significant. However, the response became negative thereafter and significant between 2.5 and 3.5 years. But the response reaches its highest decline at the third year while maintaining the negative response at a declining rate up to the 6th year before the effect died out. In other words, the effect of carbon emission on AGP is significant and negative between 2.5 and 3.5 years. The maximum impact of a one standard deviation shock in CE occurred in third year resulting to about 2.6% decline in AGP. Overall, one can conclude that based on the VAR parameter estimates and impulse response functions, carbon emission has negative and significant short run effect on AGP. However, AGP does not have a significant effect on CE as can be seen from the first panel of Table 3.

The response of FS to a shock in CE is in the third panel of Figure 1. Initially there was a delayed and apparently positive response. However, the response became negative from half way into the second year until the 6th year when it consistently decreased to zero over the years that follows. However, the relationship of CE to FS is significant between the second year and half way into their fourth year. The response reaches its highest decline at the third year with a negative impact of 2.5 percent at that time. One can therefore conclude that the effect of CE on FS is negative and significant in the short run. However, FS does not have a significant effect on CE.

Table 3. VAR estimates of the short run relationship

	CE	AGP	FS
CE(−1)	0.096	−0.060*	−0.058*
	(−0.156)	(−0.033)	(−0.033)
	[0.616]	[−1.836]	[−1.744]
CE(−2)	−0.022	−0.089**	−0.085**
	(−0.165)	(−0.035)	(−0.035)
	[−0.131]	[−2.566]	[−2.442]
AGP(−1)	−1.434	0.612	0.479
	(−14.278)	(−2.999)	(−3.021)
	[−0.100]	[0.204]	[0.159]
AGP(−2)	−14.051	−3.766	−4.053
	(−13.541)	(−2.844)	(−2.865)
	[−1.038]	[−1.324]	[−1.415]
FS(−1)	0.702	−0.545	−0.402
	(−14.205)	(−2.983)	(−3.005)
	[0.049]	[−0.183]	[−0.134]
FS(−2)	14.834	3.774	4.064
	(−13.548)	(−2.845)	(−2.866)
	[1.095]	[1.326]	[1.418]
Constant	0.438	0.119	0.103
	(−0.389)	(−0.082)	(−0.082)
	[1.124]	[1.451]	[1.254]
R^2	0.082	0.253	0.241
F-statistic	0.593	2.260	2.116

Note: Standard errors in parenthesis and *t*-statistics in square brackets.

*Indicate significance at 10 percent.

**5 percent level, respectively.

Overall, the analysis so far has shown that carbon emission has a negative and significant effect on both AGP and FS. Therefore the null hypothesis that there is no short run relationship between CE, AGP and FS in Nigeria is rejected. As a digression, it can also be observed that FS responds positively and significantly to a shock in AGP but not vice versa (Figure 2).

Variance decomposition shows the proportion of the forecast error variance of a variable that can be attributed to its own innovations and that of other variables (Iwayemi & Fowowe, 2010). It shows the percentage error in one variable due to one standard deviation shock of the variable itself (own shocks or variations) and other variables in the system (Alege, 2010). It is majorly used for the purpose of making reasonable forecasts of variables in the model over a specified time period. The variance decomposition analysis was conducted for ten horizons (i.e. ten years). The results for year 1, 5, and 10 are presented in Table 4 for brevity. From the first panel of Table 4 it can be seen that 100 percent of changes in CE is explained by changes in own shock or innovations in the first year, but in the fifth and tenth period the proportion explained by CE declined to 92.86–93.55 percent, respectively. Also, the results reveal that only about 4.73 and 2.41 percent of changes in CE is explained by changes in AGP and FS, respectively, in the 5th year, although with very minute increases to 4.88 and 2.59 percent, respectively, in the tenth year. This means that carbon emission is majorly influenced by changes in its own shock and not changes in AGP and FS, thus appropriate enactment of relevant policy by government is necessary.

Figure 2. Impulse responses.

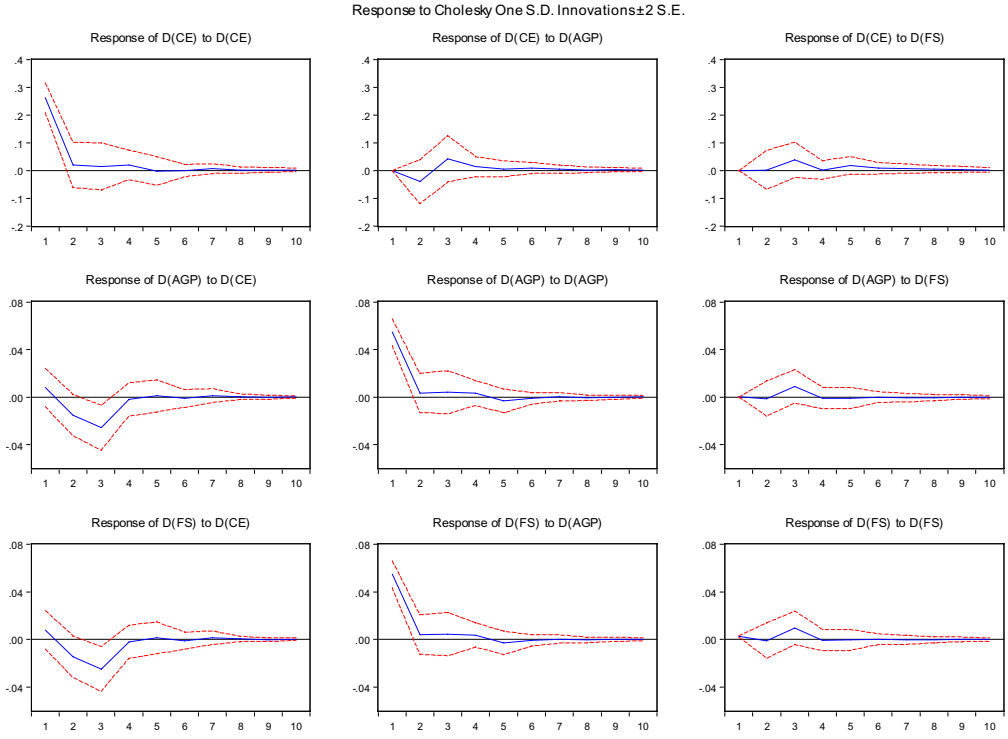


Table 4 also shows that 97.89 percent of changes in AGP are explained by changes in its own shock. However by the fifth and tenth periods CE explained about 24 percent of changes in AGP while FS explained about 2 percent of the changes in AGP in the fifth and tenth periods. More so, the variance decomposition in the third panel shows that although the variation in FS is largely due to changes in AGP accounting for 97.7 percent in the first year, then dropped to 75.4 percent in the fifth and tenth periods. This is then followed by changes in carbon emission which contributed 2.1 percent in the first year and increased to 22.0–22.1 percents in the fifth and tenth periods.

From the foregoing analysis of the VAR parameter estimates, impulse response functions and variance decomposition, it is very clear that CE plays a significant role in the changes in AGP and FS at least in the short run. Therefore, the null hypothesis that CE does not have short run relationship with AGP and FS is rejected.

3.4. Causal relationship between CE and AGP and between CE and FS

Granger causality test is use to determine whether there is feedback or causation from one variable to another and the direction of such causality (Okodua & Olayiwola, 2009). VAR-based Granger causality was used to determine whether there is any form of causality between the variables and the direction of such causality. The causality tests were done using the first differenced series. The Granger causality tests between CE and AGP is presented in Table 5. The results show a unidirectional causality running from CE to AGP, meaning that CE Granger causes AGP. Therefore, the null hypothesis that there is no significant causal relationship between CE and AGP in Nigeria is rejected at 1% level. This finding is consistent with Cline (2008) who found that the impact of baseline global warming by the 2080s is a reduction in AGP (output per hectare) of 16 percent without carbon fertilization, and a reduction of 3 percent should carbon fertilization benefits actually materialize. Further, the unidirectional causality result is consistent with Joo, Kim, and Yoo (2015) who found that there is unidirectional causal running from CE to economic growth and not vice versa.

Table 4. Variance decomposition

Period	CE	AGP	FS
Variance decomposition of CO_2 emission			
1	100.000	0.000	0.000
5	92.862	4.732	2.406
10	92.546	4.868	2.586
Variance decomposition of agricultural productivity			
1	2.115	97.885	0.000
5	23.794	74.151	2.055
10	23.839	74.095	2.066
Variance decomposition of food security			
1	2.100	97.701	0.199
5	22.048	75.440	2.512
10	22.097	75.388	2.515

Table 5. Granger causality tests between CE and AGP and between CE and FS

Null hypothesis	*F*-statistic	Probability
AGP does not Granger cause CE	1.395	0.498
CE does not Granger cause AGP	10.948***	0.004
FS does not Granger cause CE	1.487	0.476
CE does not Granger cause FS	9.902***	0.007

***Indicates significance at 1% level.

This study's estimates underscore the importance of coordinated international action to limit carbon (iv) oxide emissions and avert warming and damage that will likely otherwise occur. Policymakers should therefore implement policies that will stimulate increased AGP such as carbon sequestration, reduction in industrial activities that have been identified to be major sources of carbon and other GHGs which will not only boost AGP.

The Granger causality test result in the third row suggests that FS does not Granger cause CE. This implies that FS has no predictive ability for CE. However in row 4 the result indicates that CE Granger causes FS. Therefore, the null hypothesis that there is no significant causal relationship between CE and FS in Nigeria is rejected at 1% level. This study hence provides evidence of unidirectional causality from CE to FS. This means that FS can be predicted with CE. In other words CE has predictive power for FS. This is not surprising given that CE has a negative effect on AGP which in turn affects FS. It is therefore important that policies and interventions that can help reduce CE be promoted since these will boost the FS status of Nigeria.

That neither AGP nor FS Granger caused CE could be explained by the fact that the agricultural sector in Nigeria may be too small to predict or lead CE. CO_2 is more of a global pollutant than local. Moreover, the sector is dominated by small-scale farmers whose production activities are less energy-dependent and this may limit the amount of CE from this sector. This is not surprising given the view that more advanced economies have higher energy and CE intensities than less developed economies. This is not however to say that Nigeria should not join the global economy in aiming at producing food with less CE. This can only be avoided in the short term. The results may rather suggest that improving the way food produced in Nigeria is not the only way to improve the quality of the environment; other factors may come into play.

4. Conclusion and policy implications

This study examined the dynamic relationship among CE, AGP, and FS in Nigeria. Results show that the variables are non-stationary in levels but stationary in their first differences. The empirical analysis of the study shows that there is a negative short run relationship between CE and AGP and between FS but no long run relationship between CE, AGP and FS in Nigeria. Further, there is a unidirectional causal relationship between CE, AGP and FS with causality running from CE to AGP but not vice versa. Similar result was obtained in the case of CE and FS. Also changes in FS are largely due to changes in AGP aside the effect of CE.

The absence of long-run impacts in our analysis should not be interpreted as the absence of CEs impact on AGP and FS and hence welfare of households. CEs create a negative externality as it harms others in a way that is not reflected in the price of carbon-based energy. This happens regardless of in the short or long run. Because the price of carbon-based energy does not reflect the full costs, or economic damages, of CEs, market forces result in a level of CEs that is too high resulting to market failure. Therefore, public policies are needed to reduce CEs and to limit its further damage. Based on the findings which show that CEs has a negative effect on AGP and FS and also have a predictive ability for these two variables of interest, it is therefore recommended that: policies should be timed appropriately in order to have the desired effect on the economy and at the right time; interventions programs and/or policies such as investment in research and development, cap and trade system, carbon tax policy, adoption of clean power plan, and other regulatory measures should be designed in such a way as to mitigate the effect of CO_2 and possibly reduce its chances of emission to the barest minimum. For instance, some new technologies that can absorb excess CO_2 are currently being proposed and/or developed by Chemical and Petrochemical engineers, hence companies responsible for emitting much of the CO_2 can be mandated to purchase and use such technologies. Government can consider adopting the carbon tax policy, government should reinforce mitigation and adaptation practices in order to boost AGP and FS. It is recommended that government through extension workers in the various states ensures farmers are aware of the effects of CE and to educate them on the different adaptation strategies in order to boost AGP and FS. Finally, policy-makers should implement policies that will stimulate increased AGP such as carbon sequestration, reduction in industrial activities that have been identified to be major sources of carbon and other GHGs which will not only boost AGP but also promote FS. Delaying action is costly and may ultimately lead to higher CO_2 concentrations, consequently producing additional damages to the economy as a result of higher temperatures, more acidic oceans, and other consequences of higher CO_2 concentrations. Future studies in this area may examine whether the relationship between CE, AGP and FS is nonlinear or time-varying since the current study is based on a linear model.

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Appendix 1

Table A1. VAR lag order selection criteria

Lag	Log *L*	LR	FPE	AIC	SC	HQ
0	−13.522	NA	0.000	0.718	0.838	0.763
1	279.803	8.435	0.000	−11.687	−10.852	−11.374
2	284.829	544.815*	1.42e−09*	−11.862*	−11.385*	−11.683*
3	300.383	16.560	0.000	−11.756	−10.563	−11.309
4	306.046	8.125	0.000	−11.611	−10.060	−11.030

*Lag order selected by the criterion.

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