# Foreign direct Investment and carbon emissions nexus in Nigeria: Evidence from nonlinear ARDL and causality approaches

**Anthony Enisan Akinlo[a,*] and Taiwo Akinlo[b]**
[a]*Department of Economics, Obafemi Awolowo University, Ile-Ife, Nigeria.*
[b]*Department of Economics, Adeyemi Federal University of Education, Ondo, Nigeria.*

*Corresponding author: aakinlo@oauife.edu.ng

**ABSTRACT**

The study examines the asymmetric effects of foreign direct investment on carbon emissions and ascertains the direction of causality between them. Employing annual data series from 1980 to 2022, the study uses autoregressive distributed lag model, vector error-correction modelling, and Granger causality approaches to achieve the objectives. The nonlinear bounds test supports a cointegration relationship among the variables employed in the model. Moreover, the results confirm the asymmetry effect of foreign direct investment on carbon emissions in the short run but not in the long run. The results show that positive shocks in foreign direct investment have a reducing insignificant effect on carbon emissions. Likewise, negative shocks in foreign direct investment have a significant, reducing effect on carbon emissions. Trade openness, energy use, and the ratio of private sector's credit to GDP reduce carbon emissions, while per capita income and oil price increase it. The study is significant as it shows that carbon emissions respond differently to changes in foreign direct investment in the short run only. Therefore, policymakers should encourage more FDI inflows through improved credits and increased trade openness. However, they must promote the adoption of low-carbon and environmentally friendly technologies that will facilitate the attainment of the same or even higher output at lower carbon emissions in the country.

**KEYWORDS**: C24, F21, Q52, Q56
**JEL classification**: Foreign direct investment, carbon emissions, asymmetry, nonlinear ARDL, Nigeria

## 1. Introduction

The debate on the link between carbon emissions (Co2) and foreign direct investment (fdi) continues worldwide. The debate remains a hot topic because while fdi enhances economic growth, facilitates knowledge transfer, promotes exports, and enables human capital augmentation, it equally poses a lot of challenges to the environmental quality of the host countries. Existing studies on Co2 emissions and fdi nexus have yet to produce conclusive evidence. In general, one can identify two main perspectives on the link between fdi and Co2 emissions, namely pollution halo and pollution haven hypotheses. The pollution haven hypothesis contends that fdi hurts the host country's environment, especially in countries with lax environmental regulations. On the other hand, the pollution halo hypothesis opines that the technological and capital investment occasioned by fdi will positively impact the host country's quality of environment.

Extensive empirical literature has examined the fdi-Co2 emissions nexus worldwide. Some studies find that Co2 emissions increase with an increase in fdi inflows (Peng et al. 2016, Behera and Dash 2017, Gong et al., 2021, Ashraf et al., 2022). Yet, few other studies contend that fdi helps to reduce Co2 emissions (Kim and Adilov 2012, Bao et al. 2011, Solarin and Al-Mulali 2018, Huang et al., 2019, Demena and Afesorgbor 2020). However, possibly due to the relatively low level of Co2 emissions and FDI in SSA, in comparison with other continents and sub-regions such as Asia, Latin America, Europe, and Central America, only a few studies have explored the fdi and Co2 emissions nexus.

Looking at Nigeria, a number of factors suggest that fdi may increase Co2 emissions. Firstly, the environmental regulations are weak in the country as against the tough or highly restrictive environmental regulations in the developed nations. More often than not, multinational firms usually capitalize on the lax environmental regulations to indulge in 'dirty' activities in the country. Secondly, considering the high level of corruption in Nigeria, it is most likely that these multinational firms will buy their way into the country without complying with even the weak environmental regulations, thereby becoming pollution haven. Indeed, in the words of Cole et al. (2006), "if the host countries' experience a high level of corruption, the presence of multinational firms encourages weaker environmental regulations and leads to the creation of pollution haven."

Given the apprehensions as regards the possible adverse impact of fdi on environmental quality, it becomes important to empirically ascertain the situation in Nigeria. It is important to address the questions that follow. One, are foreign direct investment and carbon emissions cointegrated? Two, how does fdi impact Co2 emissions? Three, is the relationship linear or nonlinear? Four, what is the direction of causation between fdi and carbon emissions? Following from the questions above, the objectives of this work are: one, determine whether or not carbon emissions and foreign direct investment are cointegrated; two, determine whether the relationship between fdi and carbon emissions is linear or nonlinear; three, examine the asymmetric effects of foreign direct investment on carbon emissions, and finally, determine the direction of causality between, foreign direct investment and carbon emissions.

This study is significant for several reasons. Firstly, the findings from the analysis will help determine the most appropriate way of modelling the effect of foreign direct investment and carbon emissions. Understanding how the relation between foreign direct investment and carbon emissions should be modelled is critical to the formulation of appropriate direct investment policies that support sustainable development. Secondly, knowledge of the effects of such variables as trade openness, credit to the private sector, urbanization among others will assist policymakers to articulating reforms and policies that promote inflows of environmentally foreign direct investment into the economy.

The remainder of the paper is structured thus: Section 2 provides the theoretical and empirical review. In section 3, we describe the data and methodology. The empirical results and discussion are provided in section 4. The last section provides the conclusions.

## 2. Theoretical and empirical issues

In this section, we provide a summary of theoretical and empirical literature review of the impact of foreign direct investment on carbon emissions[1].

### 2.1. Review of Theories

Theoretically, the association between Co2 emissions and fdi is analyzed under two hypotheses, namely the pollution halo and the pollution haven. The pollution haven hypothesis propounded by Walter and Ugelow (1979) opines that multinational firms faced with strict environmental management regulations, policies, and enormous compliance costs for production activities in their home countries tend to locate and/or relocate environmentally damaging production activities to resource-rich developing countries with lax environmental regulations. This action often precipitates environmental degradation in the host countries. Thus, the pollution haven hypothesis contends that fdi inflows will adversely affect the quality of the environment of the host country.

In contrast, the pollution halo theory says that the fdi inflows enhance the spillover of more environmentally friendly production technologies by multinationals, which assists in promoting industrial upgrading in the host countries. The proponents contend that fdi from developed countries enhances ecological sustainability in the host countries as environmentally sound technologies are transferred by multinational firms (Zarsky 1999, Kim and Adilov 2012, Zhu et al. 2016, Eskeland and Harrison 2006). In short, fdi inflows will assist in promoting technology and sound management practices, thereby lowering Co2 emissions in the host countries[2].

[1] For a detailed literature survey, see Wang et al. (2023), Limazie and Woni (2024), Apergis et al (2023) and Huang et al (2022)

[2] A variant of the halo hypothesis is the Porter's hypothesis (Porter and van der Linde 1995). It says that stringent environmental regulations can induce firms to undertake more technological innovation, which may bring more environmentally friendly and energy efficient production technologies with positive effect on the environment (for details literature survey on these hypotheses, see Wang et al. 2022, Opoku et al. 2021).

### 2.2. Empirical Literature

Several studies have probed the nexus between Co2 and fdi with divergent results/findings. Mostly, their findings are dependent on the countries studied and the estimation techniques employed. Some of these results confirmed the pollution haven hypothesis for many countries (see, for example, Cole 2004, Jiang 2015, Opoku and Boachie 2020, De Pascale et al., 2020, Nasir et al., 2019). Likewise, many other studies have provided findings in support of the pollution halo hypothesis including Kim and Adilov 2012, Bao et al. 2011, Zugravu-Soilita 2017, Solarin and Al-Mulali 2018, Demena and Afesorgbor, 2020)[3].

Although, many existing studies have investigated the link between Co2 emissions and fdi, only a few existing empirical studies focused exclusively on Sub-Saharan Africa. These include Acheampong (2019), Maji et al. (2016), Adams and Opoku (2020), Opoku et al. (2021), Mahmood et al. (2019), and Opoku and Boachie (2020). Adams and Opoku's (2020) study for 22 SSA using the system GMM corroborates the pollution haven hypothesis, while Opoku and Boachie (2020) for 36 African countries using the PMG validate pollution haven. Similarly, Opoku et al. (2021) for 22 SSA countries confirm the pollution halo hypothesis. Country-specific cases by Mahmood et al. (2019) and Maji et al. (2016) for Egypt and Nigeria respectively, confirm the pollution halo theory. Likewise, Odugbesan and Adebayo's (2020) for Nigeria. However, Solarin et al. (2017) for Ghana confirm the pollution haven hypothesis. Generally, the few known existing studies on the fdi-Co2 nexus in SSA do not consider the possibility of an asymmetrical relationship, except Odugbesan and Adebayo (2020). In this study, we not only examine the asymmetric relationship between foreign and carbon emissions but also investigate the causal relations between the two phenomena in the case of Nigeria.

## 3. Methodology

### 3.1. Data and Data Sources

The study utilizes annual data from 1980 to 2022 for the estimation of the model. The variables employed in our analysis are carbon emissions (Co2), foreign direct investment (fdi), trade openness (top), the ratio of the private sector's credit to GDP (cpp), energy use (ent), per capita income (pci), oil price (oip), urbanization (urb). Data employed are sourced from the World Development Indicators database (World Bank). The price of oil (US$ per barrel) is sourced from the BP Statistical Review of World Energy. All the variables employed are in natural logarithms form. The definitions of variables and the sources of data are presented in Table 1.

**Table 1**
Definition of Variables and Data sources

| Variables | Definition of variables and sources of data |
|---|---|
| cpp | credit to the private sector. Source: CBN Statistical Bulletin (2023) |
| oip | price of oil (US $ per barrel). Source: BP Statistical Review of World Energy (2023) |
| ent | energy use. Source: World Development Indicators (2023) |
| urb | urbanization. Source: CBN Statistical Bulletin (2023 edition) |
| Co2 | carbon emissions (millions metric tons). Source: World Development Indicators (2023). |
| pci | per capita income. |
| top | trade openness. Export plus imports over GDP |
| fdi | foreign direct investment |

Notes: The table presents the definitions and the sources of the variables used in our model.

### 3.2. Model Specification

[3] Few of the existing studies have provided a comprehensive review of literature on FDI-Carbon emissions nexus (see for example, Khan et al. 2023, Apergis et al. 2023, and Opoku et al 2021).

Our empirical analysis is carried out using a variant of Dietz and Rosa's (1994) Stochastic Impacts by Regression of Population, Affluence, and Technology (STIRPAT) model incorporating explicitly foreign direct investment (fdi) as an argument. The model explicitly stated is:

$Co2_t = (fdi_t, top_t, cpp_t, ent_t, pci_t, oip_t, urb_t)$ (1)

Equation (1) is stated explicitly as:

$Co2_t = \alpha_0 + \alpha_1 fdi_t + \alpha_2 top_t + \alpha_3 cpp_t + \alpha_4 ent_t + \alpha_5 pci_t + \alpha_6 oip_t + \alpha_7 oip_t + \alpha_8 urb_t + \varepsilon t$ (2)

where *Co2* is carbon emissions, cpp denotes private sector's credit to GDP ratio, fdi is foreign direct investment, top is trade openness, pci is per capita income, ent represents energy use, and oip denotes price of oil, urb represents urbanization and $\varepsilon$ denotes the residual. As arguments in the carbon emissions' determinants model, the existing literature accounts for urbanization (see, e.g. Hossain 2011, Al-Mulali and Ozturk 2015, Nadeem et al. 2020. Sarkodie and Ozturk 2020, Murshed et al. 2021, Anwar et al. 2022), energy use (see, e.g. Charfeddine and Kahia 2019, Ambe 2021, Chen et al. 2022, Rahman et al 2022), per capita income (see, e.g. Dogan et al. 2022, Jahanger et al. 2022, Opoku et al. 2020), trade openness (see, e.g. Hossain 2011, Al-Mulali and Otzurk 2015, Zhang 2020, Lee et al. 2016), oil price (see, e. g. Ullah et al. 2020, Agbanike et al. 2019, Li et al. 2018, Li et al 2020), credit to the private sector (see e.g. Jalil and Feridun 2011, Tamazian et al. 2009, Zhao et al 2021) and fdi (see. e.g. Apergis et al. 2023, Boateng et al. 2024, Limazie and Woni 2024, Wang et al. 2020, Abdul-Mumuni et al. 2023, Gao et al. 2022, Wang and Zhang 2022, Zugravu-Soilita 2017). As our dependent variable, we use carbon emissions (CO2) measured in metric tons. The use of carbon emission as a measure of environmental pollution is extant in the literature (see, e.g. Ullah et al. 2020, Apergis 2023, Boateng et al. 2024). In line with Pesaran et al. (2001), the unrestricted error correction of an equation (2) is given thus:

$$\begin{aligned}\Delta Co2_t = {} & \delta_0 + \delta_1 Co2_{t-1} + \delta_2 fdi_{t-1} + \delta_3 top_{t-1} + \delta_4 cpp_{t-1} + \delta_5 ent_{t-1} + \delta_6 pci_{t-1} + \delta_7 oip_{t-1} \\ & + \delta_8 urb_{t-1} + \sum_{i=1}^{n} \beta_1 \, Co2_{t-i} + \sum_{i=0}^{p} \beta_2 \, fdi_{t-i} + \sum_{i=0}^{q} \beta_3 \, top_{t-i} + \sum_{i=0}^{r} \beta_4 cpp_{t-i} \\ & + \sum_{i=0}^{s} \beta_5 \, ent_{t-i} + \sum_{i=0}^{q} \beta_6 \, pci_{t-i} + \sum_{i=0}^{w} \beta_7 oip_{t-i} + \sum_{i=0}^{x} \beta_8 urb_{t-i} \\ & + \varepsilon_t \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots (3)\end{aligned}$$

To account for asymmetries in the relation between fdi and Co2 emissions, we decompose fdi into positive and negative partial sums ($fdi_t^+, fdi_t^-$) in line with Shin et al. (2014). The positive and negative partial sums are generated as shown in Equation 4.

$$fdi_t^+ = \sum_{j=1}^{m} \Delta fdi_j^+ = \sum_{j=1}^{m} \max(\Delta fdi_j \, , 0)$$

$$fdi_t^- = \sum_{j=1}^{m} \Delta fdi_j^- = \sum_{j=1}^{m} \min(\Delta fdi_j \, , 0) \quad \dots\dots\dots (4)$$

Following Shin et al. (2014), if we substitute equation (4) into (3), we obtain a nonlinear ARDL (NARDL) given as in (5):

$$\begin{aligned}\Delta Co2_t = {} & \delta_0 + \delta_1 Co2_{t-1} + \delta_2^+ fdi_{t-1}^+ + \delta_3^- fdi_{t-1}^- + \delta_4 top_{t-1} + \delta_5 cpp_{t-1} + \delta_6 ent_{t-1} + \delta_7 pci_{t-1} \\ & + \delta_8 oip_{t-1} + \delta_9 urb_{t-1} + \sum_{i=1}^{n} \beta_1 \Delta Co2_{t-i} + \sum_{i=0}^{m} \beta_2 top_{t-i} + \sum_{i=0}^{x} \beta_3 cpp_{t-i} \\ & + \sum_{i=0}^{r} \beta_4 \Delta ent_{t-i} + \sum_{i=0}^{y} \beta_5 \Delta pci_{t-i} + \sum_{i=0}^{v} \beta_6 oip_{t-i} + \sum_{i=0}^{z} \beta_7 urb_{t-i} + \sum_{i=0}^{s} (\beta_8^+ fdi_{t-i}^+ \\ & + \beta_8^- fdi_{t-i}^-) + \mu_t \dots\dots\dots.. (5)\end{aligned}$$

where v, r, z, m, n, s, x, and y are lag orders, while ($fdi^+$, $fdi^-$) are the positive and negative partial sums as defined in equation (4). These innovations as included equation 5, are used to ascertain short- and long-run asymmetric responses of carbon emissions to changes in foreign direct investment.

To ascertain the long-run asymmetric effect of the foreign direct investment changes in equation (5), we employ the Wald test with the null hypothesis ($\delta_2^+ = \delta_3^-$). The long-run impact of positive fdi (*fdi*$^+$) is obtained as $B^+$ = - ($\delta_2^+/\delta_1$), while the negative changes in fdi (*fdi*$^-$) on Co2 emissions is given as $B^-$ = - ($\delta_3^-/\delta_1$). In contrast, we employ the Wald test to determine the short-run asymmetry of fdi with the null hypothesis of this test as: ($\beta_8^+ = \beta_8^-$).

Following, we utilize the NARDL model as specified in equation (5) to obtain the dynamic multipliers (DM, hereafter), $m_h^+$ and $m_h^-$, where $m_h^+$ is for the change in $fdi_t^+$ while $m_h^-$ relates to the change in $fdi_t^-$:

$$m_h^+ = \sum_{i=0}^{h} \frac{\partial Co2_{t+i}}{\partial fdi_{t-1}^+}, \qquad m_h^- = \sum_{i=0}^{h} \frac{\partial Co2_{t+i}}{\partial fdi_{t-1}^-} \qquad h = 0, 1, 2 \quad \ldots\ldots\ldots (6)$$

$$Note\ that\ as\ h \longrightarrow \infty,\quad m_h^+ \longrightarrow \beta^+, and\ m_h^- \longrightarrow \beta^-$$

Next, the unit roots properties of the variables are verified to obviate the inclusion of I(2) variables. To achieve the first objective i.e. determining whether the variables are cointegrated, we conduct cointegration test. This involves testing the null hypothesis of no cointegration ($H_0$: $\delta_1 = \delta_2 = \ldots = \delta_9 = 0$) against an alternative hypothesis ($H_1$: $\delta_1 \neq \delta_2 \neq \ldots \neq \delta_9 \neq 0$) using the F-test. The variables are cointegrated when the computed value of the F-statistic falls outside the upper critical value of the two sets of critical values provided by Pesaran et al. (2001). The objective of determining the asymmetric effect of foreign direct investment on carbon emissions is achieve by estimating nonlinear ARDL (NARDL) equation (5) and then employing the Wald test to ascertain the long- and short run asymmetric effects. Finally, the objective of determining the direction of causality is achieved by estimating a multivariate error correction model (VECM) with special focus on the variance decompositions (VDCs), Impulse Response Functions (IRFs) and Block Exogeneity Wald test.

**4. Empirical Results**

The descriptive statistics and pairwise correlations of the data series are shown in Tables 2 and 3, respectively. From Table 2, carbon emissions, trade openness, the ratio of private sector credit to GDP, per capita income, and urbanization are platykurtic as their kurtosis values are less than 3. This shows that these variables have lighter tails than a normal distribution. The reverse is the case for foreign direct investment, energy use, and oil price whose kurtosis are greater than 3. From table 2, per capita income has the highest mean, while the ratio of private sector credit to GDP has the lowest. Co2 emissions and private sector's credit to GDP ratio have the lowest values compared to other variables. This suggests that that private sector's credit to GDP ratio and carbon emissions series are steady from 1980-2022. The coefficient of correlation of the independent variables is less than 0.7, thus ruling out the likelihood of multicollinearity between the independent and dependent variables (see Table 3). The pair-wise correlation results reveal that all the independent variables are negatively related to carbon emissions.

**Table 2**
Descriptive statistics

| | *CO2* | *fdi* | *top* | *cpp* | *ent* | *pci* | *oip* | *urb* |
|---|---|---|---|---|---|---|---|---|
| Mean | 0.605 | 1.457 | 32.306 | 0.115 | 662.639 | 31581.80 | 41.426 | 36.224 |
| Median | 0.588 | 1.090 | 34.020 | 0.082 | 693.970 | 6897.480 | 29.040 | 34.800 |
| Maximum | 0.928 | 5.790 | 53.280 | 0.247 | 798.630 | 129397.0 | 109.45 | 52.000 |
| Minimum | 0.326 | 0.010 | 9.140 | 0.059 | 333.973 | 137.590 | 12.280 | 22.000 |
| Std. Dev | 0.170 | 1.252 | 12.616 | 0.558 | 85.933 | 42209.87 | 28.742 | 8.822 |
| Skewness | 0.023 | 1.709 | -0.333 | 0.847 | -2.570 | 1.150 | 1.127 | 0.176 |
| Kurtosis | 2.039 | 6.026 | 2.134 | 2.058 | 10.776 | 2.866 | 3.121 | 1.888 |
| Jarq-Bera | 1.582 | 35.598 | 2.034 | 6.425 | 148.433 | 9.070 | 8.705 | 2.326 |
| Probability | 0.453 | 0.000 | 0.361 | 0.040 | 0.000 | 0.011 | 0.013 | 0.312 |
| Sum | 24.795 | 59.750 | 1324.560 | 4.701 | 27988.19 | 1294854.0 | 1698.460 | 1485.200 |
| Sum Sq.Dev | 1.163 | 62.701 | 6366.872 | 0.136 | 295382.5 | 7.13E+10 | 33045.10 | 3113.116 |

Notes: The table represents descriptive statistics for the variables in our model. Carbon emissions (CO2), foreign direct investment (fdi), trade openness (top), credit to the private sector (cpp), energy use (ent), per capita income (pci), oil prices (oip), and urbanization (urb)

**Table 3**
Pairwise-Correlation matrix

| Variable | *CO2* | *fdi* | *top* | *cpp* | *ent* | *pci* | *oip* | *urb* |
|---|---|---|---|---|---|---|---|---|
| ***CO2*** | 1.000 | | | | | | | |
| ***fdi*** | -0.303 | 1.000 | | | | | | |
| ***top*** | -0.251 | 0.479 | 1.000 | | | | | |
| ***cpp*** | -0.094 | 0.218 | 0.025 | 1.000 | | | | |
| ***ent*** | -0.389 | 0.310 | 0.361 | 0.543 | 1.000 | | | |
| ***pci*** | -0.279 | 0.176 | 0.252 | 0.838 | 0.661 | 1.000 | | |
| ***oip*** | 0.232 | 0.004 | 0.162 | 0.578 | 0.434 | 0.663 | 1.000 | |
| ***urb*** | -0.278 | 0.178 | 0.248 | 0.840 | 0.654 | 0.999 | 0.881 | 1.000 |

Notes: The table presents the pairwise correlation matrix. All variables are as defined in table 1

The results of the unit roots are shown in Table 4 for level and first difference using PP and ADF. In both cases, stationarity is established for all the variables at first difference. This shows that there are no I*(2)* variables; hence we can rely upon the ARDL estimation method.

**Table 4**
Unit root results.

| | ADF | | PP | |
|---|---|---|---|---|
| **Serial Name** | **Level** | **First Difference** | **Level** | **First Difference** |
| Co2 | -2.095 | -4.211*** | -2.149 | -6.261*** |
| fdi | -1.979 | -5.225*** | -4.505 | -9.245*** |
| top | -1.863 | -4.801*** | -2.400 | -8.104*** |
| lent | -2.242 | -3.231** | -2.271 | -7.356*** |
| cpp | -0.893 | -5.620*** | -0.799 | -5.838*** |
| pci | -1.686 | -3.049** | -1.182 | -2.944** |
| oip | -0.904 | -4.988*** | -0.942 | -6.234*** |
| urb | -1.771 | -5.147*** | -2.088 | -8.883*** |

Notes: The table presents the results of the unit root tests. *, ** and *** denote significance levels for 10%, 5%, and 1%, respectively.

After ascertaining the unit root properties of the variables, we test for cointegration among them in the linear and nonlinear models. Table 5 presents the results of the bounds test. The F- statistic value (F_pss =3.372) for the linear ARDL model lies between the lower and upper bounds of the critical values at a 5% significance level. Hence, it is indeterminate. However, for the nonlinear ARDL model, the F-statistic value (F_pss =3.967) lies above the upper bound of the critical values at a 5% significance level, confirming cointegration among the variables. This finding is consistent with the results of Abdul-Mumuni et al. (2023) for 41 Sub-Sahara African countries and Odugbesan and Adebayo (2020) for Nigeria.

**Table 5**
Results of cointegration tests for the linear and nonlinear specifications

| **Dependent Variable: $\Delta lnco2$** | **F-PSS** | **95% Lower bound** | **95% Upper bound** | **Result** |
|---|---|---|---|---|
| Linear ARDL | 3.372 | 2.597 | 3.907 | Indeterminate |
| Non-Linear ARDL[a,] | 3.967** | 2.620 | 3.879 | Cointegration |

The table shows the results of the cointegration tests for both linear ARDL and nonlinear ARDL models. [a]The exact specification of the asymmetric ARDL model is presented in Table 7. *F-PSS* indicates the *PSS F*-statistic testing the model hypothesis of no cointegration.

Next, we estimate the linear ARDL model 3, and the results are presented in Table 6. Clearly, the results are not reliable. There is evidence of specification error and serial correlation problem. Moreover, the ECM has the wrong sign. Although CUSUM and CUSUMQ tests confirm the model's stability (Fig. 1 & 2), the results look spurious. The basic question is: Will the results change considering the possibility of the asymmetric effect of foreign direct investment on carbon emissions by estimating a nonlinear ARDL model 5?

**Table 6**

Results of Linear ARDL Estimation

| **Dependent variable** | | | |
|---|---|---|---|
| **Variable** | **coefficient** | **t-statistics** | **P-value** |
| **Constant** | -20.840* | -2.369 | 0.029 |
| $CO2_{t-1}$ | 0.008*** | 0.036 | 0.971 |
| $fdi_{t-1}$ | -0.097** | -2.204 | 0.041 |
| $top_t$ | -0.127 | -1.065 | 0.301 |
| $cpp_{t-1}$ | 0.203 | 1.046 | 0.310 |
| $lent_{t-1}$ | 6.365** | 3.499 | 0.003 |
| $pci_t$ | 0.569** | 4.349 | 0.000 |
| $oip_{t-1}$ | -0.176 | -1.431 | 0.170 |
| $urb_{t-1}$ | -6.901** | -4.357 | 0.000 |
| $\Delta fdi_t$ | -0.157** | -3.157 | 0.006 |
| $\Delta cpp_t$ | -0.511** | 2.612 | 0.018 |
| $\Delta ent_t$ | -0.308 | 1.398 | 0.179 |
| $\Delta ent_{t-1}$ | -6.706** | -3.750 | 0.001 |
| $\Delta ent_{t-2}$ | -6.096** | -3.888 | 0.001 |
| $\Delta oip_t$ | 1.167 | 1.610 | 0.125 |
| $\Delta oip_{t-1}$ | 0.070 | 0.463 | 0.649 |
| $\Delta oip_{t-2}$ | -0.204 | -1.674 | 0.112 |
| $\Delta urb_t$ | -19.461 | -1.712 | 0.104 |
| $\Delta urb_{t-1}$ | 2.594 | 0.324 | 0.750 |
| $\Delta urb_{t-2}$ | 29.097** | 3.165 | 0.005 |
| **Statistics and diagnostic tests** | | | |
| $X^2_{Norm}$=0.677(0.713) | | $X^2_{Het}$ = 19.771 (0.409) | |
| $X^2_{SC}$= 5.116 (0.078) | | $X^2_{FF}$ = 5.853 (0.027) | |
| $ECM_{t-1}$ = 0.0078*** (6.621) | | *Adj.* $R^2$ = 0.630 | |

Notes: The table presents the results of the linear ARDL estimation. ** and *** indicate significance levels for 5% and 10%, respectively. and refer to LM test for serail correlation, normality, functionality form and heteroscedasticity, respectively.

To answer this question, we estimate the nonlinear ARDL model (equation 5). The estimated long- and short-run results are shown in Tables 7 and 8, respectively. Table 9 shows the results of diagnostic and asymmetric tests. As shown in Tables 7 and 9, the asymmetric impact of foreign direct investment is confirmed in the short run using the Wald test. The numerical value of the Wald test of 10.036 in the short run is statistically significant. The results indicate that carbon emissions react differently to a decrease in foreign direct investment compared to an increase in foreign direct investment in the short run but not in the long run. This finding is inconsistent with the result of Odugbesan and Adebayo (2020) for Nigeria that reported asymmetric effect of foreign direct investment on carbon emissions in the long run. Our result simply suggests that nonlinearity and asymmetry need to be taken into consideration when analyzing the foreign direct investment-carbon emissions nexus in the short run.

Next, we focus on the long- and short-run estimates. Table 7 presents the results of the long-run parameters. The coefficients of negative and positive partial sums decomposition of foreign direct investment are both negative. This means that both decrease and increase foreign direct investment will reduce carbon emissions in the long run. The long run coefficient of negative change in foreign direct investment ($fdi^-$) is -0.925, while the positive change ($fdi^+$) is -0.105 (see Table 9). This result reveals that a 1 per cent increase in foreign direct investment will lead to a 0.105 reduction in carbon emissions. This finding supports the results of Bekun et al. (2020), Odugbesan and Adebayo (2020), Opoku et al. (2021), Zhu at. 2016) and Adams and Opoku (2020). However, the coefficient is not significant. Likewise, a 1 per cent reduction in foreign direct investment will lead to a 0.925 reduction in carbon emissions. This shows that foreign direct investment is important in bringing new innovation to the country, and the outcomes demonstrate that more foreign direct investment will lead to a reduction in carbon emissions in Nigeria.

In the long run, trade openness, energy use, and urbanization have significant effects on carbon emissions. However, the private sector's credit-to-GDP ratio, per capita income, and oil price are not significantly associated with carbon emissions. In the long run, trade openness is inversely related to Co2 emissions, suggesting that opening up the economy for trade will assist in reducing Co2 emissions. This result supports the findings of Boamah et al. (2023) and Karedia et al. (2021). However, the outcome contradicts the results of Jebli et al. (2019), Zeng et al. (2019), and Khan et al. (2023). The possible reason for this finding could be that increased openness allows developed countries to shift their clean industries and more effective technology practices to the country and thus reduce Co2 emissions.

The coefficient of urbanization is negative and significant. In the long run, increased urbanization leads to a reduction in carbon emissions. This shows that urbanization improves environmental quality in the long run, supporting the ecological modernization theory. This outcome is consistent with the finding of Hashmi et al. (2021). Contrariwise, the coefficient of energy use is positive and significant. This simply suggests that increased energy use leads to increased carbon emissions. This finding aligned with Du and Xia (2018) and Ahmed et al. (2019).

**Table 7**

Long run coefficient estimates.

| Variable | Coefficient | t-statistics | ρ-value |
|---|---|---|---|
| $Co2_{t-1}$ | -0.306 | -1.452 | 0.168 |
| $top_{t-1}$ | -0.458*** | -3.154 | 0.007 |
| $cpp_{t-1}$ | 0.171 | 0.740 | 0.471 |
| $ent_{t-1}$ | 0.477** | 0.746 | 0.016 |
| $pci_{t-1}$ | 0.059 | 0.276 | 0.787 |
| $oip_{t-1}$ | 0.045 | 0.361 | 0.723 |
| $urb_{t-1}$ | -4.162*** | -3.232 | 0.006 |
| $fdi^+_{t-1}$ | -0.032 | -0.260 | 0.799 |
| $fdi^-_{t-1}$ | -0.283** | -2.085 | 0.056 |
| Constant | -16.938 | -1.339 | 0.202 |

Notes: The table presents long run estimates from the nonlinear ARDL model. *, ** and *** denote significance levels for 10%, 5%, and 1%, respectively.

The error correction term ($ecm_{t-1}$) and the short-run effects are reported in Table 8. In the short run, the results show that trade openness, the one-period lagged ratio of the private sector's credit to GDP, and energy use (ent) are negatively linked with Co2 emissions, and their coefficients are significant. In the short run, an increase in trade openness leads to a reduction in carbon emissions in line with results from long-run estimates. The current ratio of the private sector credit to GDP increases carbon emissions, while a one-period lagged value reduces it. Energy use reduces carbon emissions in the short run. It shows that more credit to the private sector may lead to the adoption of environment-friendly technologies and more effective technology management practices in the economy. In the short run, per capita income is directly related to Co2 emissions. The result supports a large body of literature showing that increased economic activities adversely impact the quality of the environment (Solarin et al. 2017, Xie et al. 2019, Khan et al. 2023). This finding corroborates the 'affluence effect', as increasing economic activities lead to increased production with adverse effect on the environment. (Wang et al. 2016, Abid 2017, Mahmood et al. 2019, Khan et al. 2023). However, the finding contradicts the results of Adewuyi and Awodumi (2017) and Zubair et al. (2020). In the same way, the coefficient of oil price is positive in the short run, meaning that increased oil price leads to increased Co2 emissions. This result, however, contradicts the findings of Mahmood et al. (2019) and Attala et al. (2018). The finding should not come as a surprise, since over the years, the oil price has been massively subsidized in Nigeria. The domestic price of oil is far below the international price; thus, even when the domestic price is increased, it has little or no effect on energy use. This simply suggests that under the present oil-subsidized regime, the energy price policy may be ineffective as a policy for reducing Co2 emissions in Nigeria. The coefficient of urbanization is positive, consistent with Omri et al.'s (2015). This suggests that increased urbanization leads to increased carbon emissions in the short run.

Finally, the results show that current positive changes in foreign direct investment have a negative and significant effect on carbon emissions in the short run. However, current and one-period lagged downward movements in foreign direct investment increase carbon emissions in the short run. The error correction term ($ecm_{t-1}$) is negative (-0.306) and significant. This shows a speed of convergence of 30.6% in a year.

**Table 8**

Results of the short-run model and error correction term

| Variable | Coefficient | t-statistics | ρ-value |
|---|---|---|---|
| Δtop | -0.198*** | -3.380 | 0.002 |
| Δcpp | 0.264*** | 3.303 | 0.003 |
| $\Delta cpp_{t-1}$ | -0.349*** | -4.152 | 0.004 |
| Δent | -2.238** | -2.419 | 0.024 |
| $\Delta ent_{t-1}$ | -4.561*** | -8.811 | 0.000 |
| Δpci | 1.254*** | 7.007 | 0.000 |
| $\Delta pci_{t-1}$ | 0.478** | 2.100 | 0.047 |
| Δoip | 0.217*** | 4.261 | 0.000 |
| Δurb | 1.045 | 0.261 | 0.796 |
| $\Delta lurb_{t-1}$ | 21.627*** | 4.356 | 0.000 |
| $\Delta fdi^{+}$ | -0.401*** | -10.037 | 0.000 |
| $\Delta fdi^{-}$ | 0.174*** | 4.943 | 0.000 |
| $\Delta fdi^{+}_{t-1}$ | -0.039 | -1.032 | 0.313 |
| $\Delta fdi^{-}_{t-1}$ | 0.224*** | 4.172 | 0.000 |
| $\Delta ecm_{t-1}$ | -0.306*** | -8.625 | 0.000 |
| Adjusted $R^2$ | | | 0.822 |

Note: The table presents results of the error-correction term and short run estimates. The variables are as earlier defined in table 1. *, ** and *** denote significance levels for 10%, 5%, and 1%, respectively.

The outcomes of the diagnostics of the estimated model are presented in Table 9. The tests for serial correlation (LM test), Normality JB test, Ramsey Reset test and heteroscedasticity, B-G test evince a well-specified estimated model. Moreover, the plots of the CUSUM and CUSUMQ statistics evince stability (see figs. 3 and 4).

**Table 9**

Diagnostic tests

| Types | Statistics |
|---|---|

| | |
|---|---|
| Serial Correlation – LM Test | 2.537(0.121) |
| Heteroskedasticity – BG Test | 22.843(0.587) |
| Normality J.B Test | 3.787(0.150) |
| Ramsey Reset Test | 2.105(0.178) |
| Long run (LR) asymmetric coefficient | |
| $LR^{+}_{fdi}$ | -0.105(0.783) |
| $LR^{-}_{fdi}$ | -0.925**(0.042) |
| Long and Short run symmetry tests | |
| $W_{LR,fdi}$ | 1.308(0.2719) |
| $W_{SR,fdi}$ | 10.036***(0.007) |

Notes: The table shows the outcomes of the diagnostic and asymmetric tests. ** and *** denote significance at 5% and 1% levels, respectively.

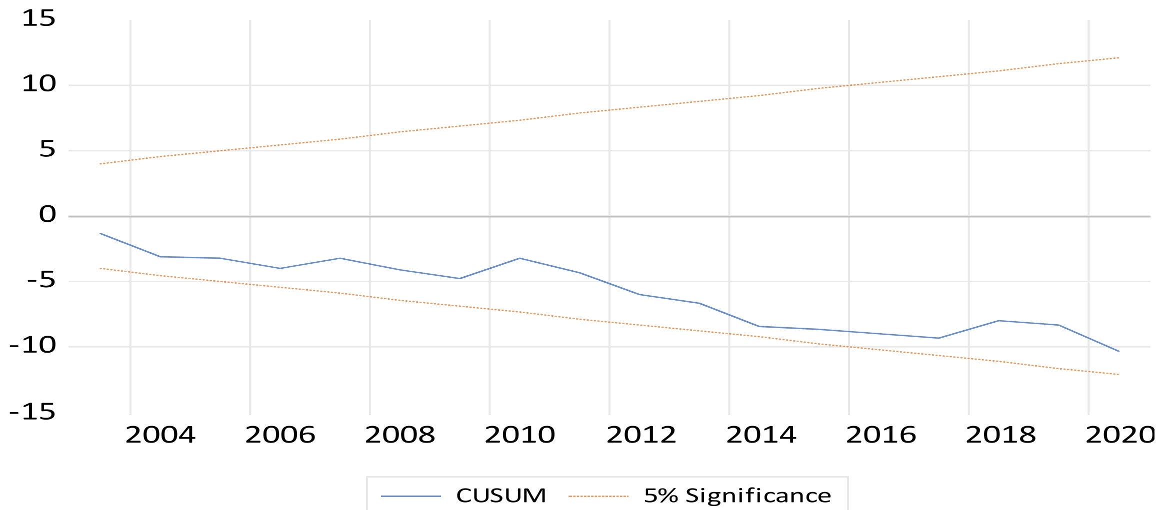


**Fig. 1.** Plot of CUSUM test for the linear ARDL model
Notes: The figure depicts the plot of CUSUM test for the linear ARDL model. It depicts the cumulative sums of the deviations of the sample values from a target value.

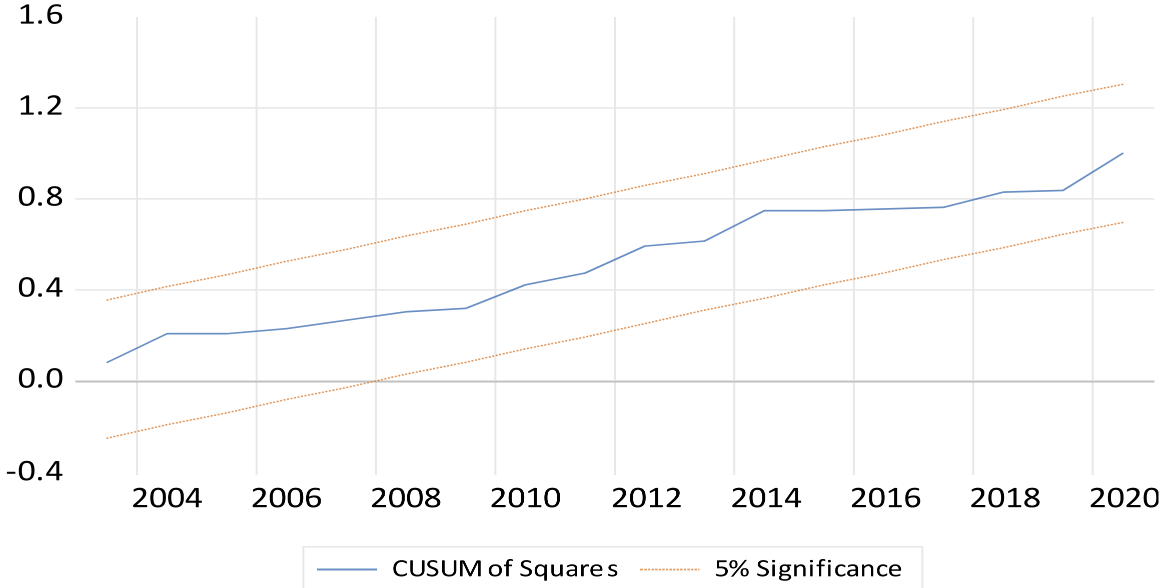


**Fig. 2.** Plot of COSUMQ test for the linear ARDL model

Notes: The figure shows plot of COSUMQ test for the linear ARDL model. It assesses the stability of regression parameters by detecting sudden changes in the variance of the error term, or the slope of coefficient.

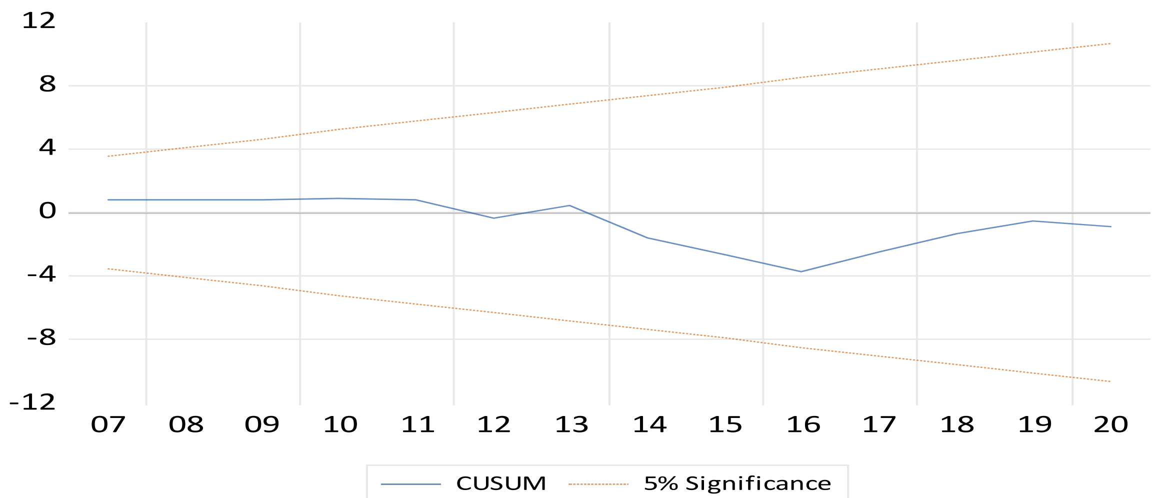


**Fig. 3.** Plot of CUSUM test for the nonlinear ARDL model

Notes: The figure depicts the plot of CUSUM test for the nonlinear ARDL model. It depicts the cumulative sums of the deviations of the sample values from a target value.

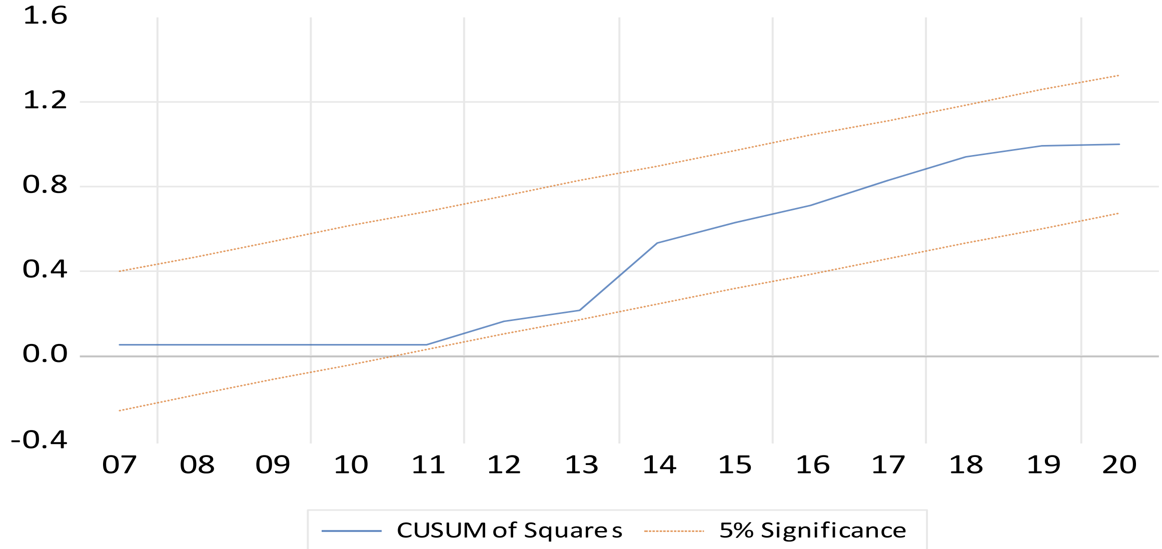


**Fig. 4.** Plot of CUSUMQ test for the nonlinear ARDL model

Notes: The figure shows plot of COSUMQ test for the nonlinear ARDL model. It assesses the stability of regression parameters by detecting sudden changes in the variance of the error term, or the slope of coefficient.

The cumulative dynamic multiplier (CDM, hereafter) shown in Fig. 5 reveals the Co2 emissions' growth pattern arising from negative and positive perturbations in fdi. The vertical axis shows the magnitude of the negative and positive perturbations, while the horizontal axis shows the time horizon. The continuous (undotted line) represents the positive shocks, while the discontinuous (dotted line) depicts the negative shocks. They reveal the impact on Co2 emissions precipitated by 5% positive/negative perturbations on fdi. Both lines show the asymmetric adjustment to positive and negative shocks at a given forecast.

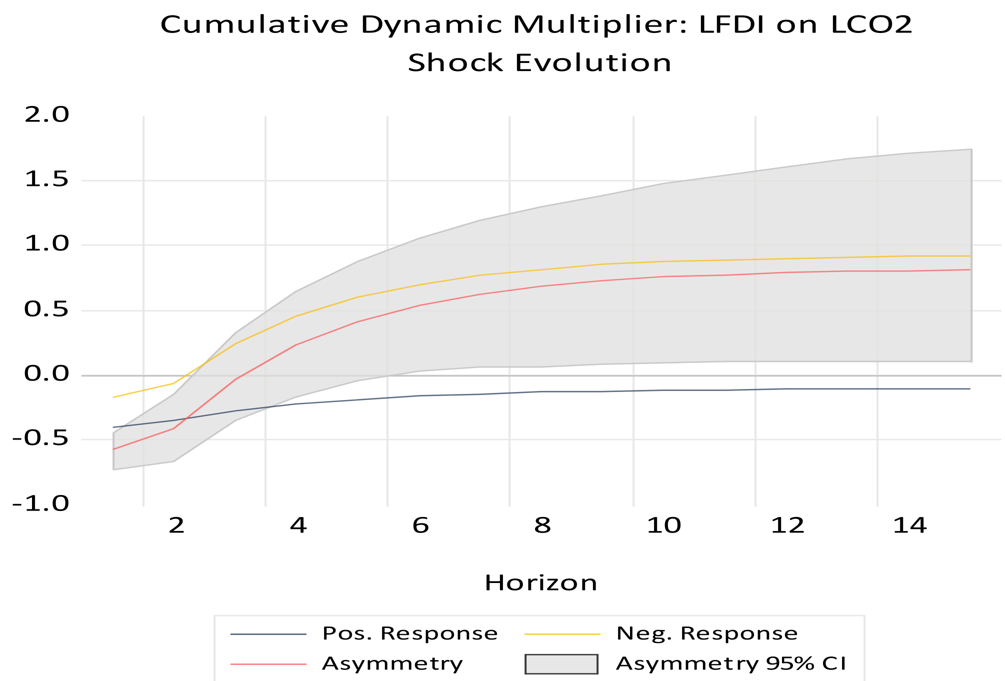


**Fig. 5.** Plot of CDM for the nonlinear ARDL Model
Notes: The figure is the chart of the cumulative causal effects up to a given lag in the the nonlinear model and measures the cumulative effect of carbon emissions of a change in foreign direct investment.

We proceed further to ascertain the dynamic interactions between foreign direct investment and carbon emissions by estimating a multivariate error correction model, a variant of model 2 that incorporates both negative and positive changes in foreign direct investment[4]. Specifically, we focus on the variance decompositions (VDCs) and the impulse response functions (IRFs) from the estimated VECM in analyzing the dynamic properties of the model[5]. Basically, the IRFs trace the dynamic responses to the effect of a shock to one variable upon itself and on all other variables, while the VDCs measure the relative contribution of each random (one-standard deviation) shock to the endogenous variables in the VECM.

Figure 5 shows the plots of the impulse response functions at 5% error bounds generated by Monte Carlo simulation for the 8-variable model. A one standard deviation shock applied to a negative change in foreign direct investment $(fdi_t^-)$ produces a sharp increase in carbon emissions in the first three periods but dips down between the third and the sixth periods. It increases marginally from the fifth to the eighth period and decreases afterwards. With respect to positive changes in foreign direct investment $((fdi_t^+)$, a one standard deviation shock applied to it causes a sharp decline in carbon emissions from the first to the fifth period. It increases carbon emissions slightly from the fifth to the seventh periods only to maintain a constant trend afterwards. Trade openness reduces carbon emissions up to the third period and increases between the third and sixth periods. It, however, drops from sixth to eighth periods with a marginal increase from eighth to the tenth period. Per capita income reduces carbon emissions sharply from the first to the seventh periods with only marginal increases from the seventh to the tenth period. Similarly, the credit to private sector-GDP ratio reduces carbon emissions sharply from the first to the sixth period; thenceforth, it maintains a constant trend. A one standard deviation shock applied to oil prices increases carbon emissions in the first two periods. It, however, reduces carbon emissions slightly from the second to the sixth period.

[4]The model estimated using vector-error correction model excludes energy use in the analysis to make estimation possible given the available data points after adjustments.
[5]Generally, the coefficients from the VECM model are difficult to interpret (see Akinlo and Akinlo 2016, Sunce and Akanbi 2016).

Finally, urbanization reduces carbon emissions from the first to the seventh period but produces no noticeable impact on carbon emissions afterwards.

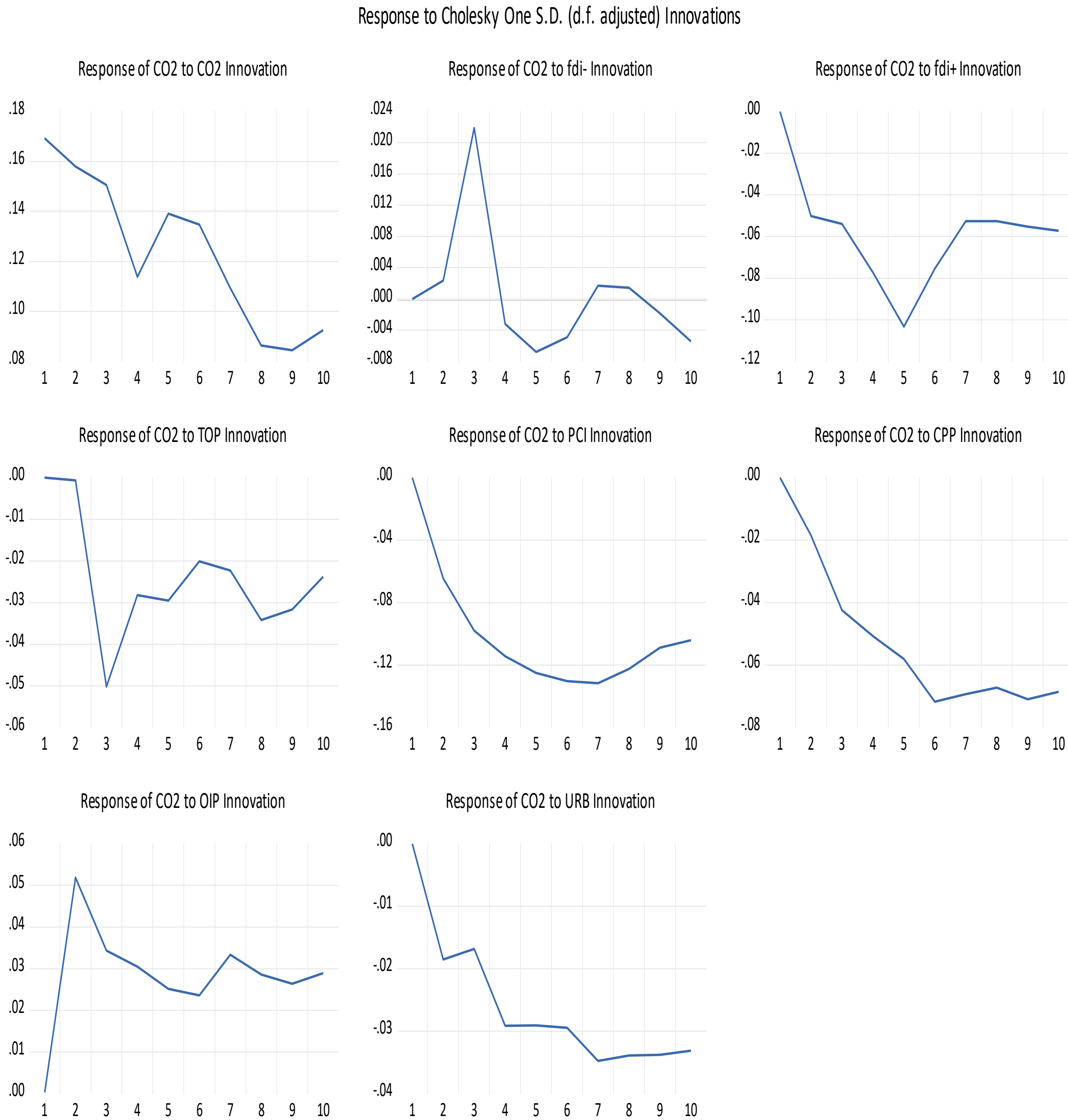


**Fig. 6.** Impulse Response Functions

Notes: The figure 6 shows Figure 5 shows the plots of the impulse response functions at 5% error bounds generated by Monte Carlo simulation for the 8-variable model. It the IRFs trace the dynamic responses to the effect of a shock to one variable upon itself and on all other variables.

The results of the VDCs are presented in Table 10**.** As revealed in the table, the proportion of variance explained by downward movement of oil prices is marginal all through the periods. The results show that negative change in foreign direct investment accounts for less than 1% variation in carbon emissions over the 10-period horizon. The proportion of variance explained by increased foreign direct investment increases from approximately 1.5% in the first period to 7% in the sixth period. It accounts for approximately 6.5% over the seventh to the tenth period.

The proportion of the variance explained by per capita income drops from approximately 9% in the first period to approximately 5% in the third period. However, the magnitude increases steadily to approximately 13% in the tenth period. The ratio of the private sector's credit to GDP has a relatively low impact in the first two periods but the magnitude increases marginally from the third period to the tenth period. It accounts for approximately 3% cent of the variation in carbon emissions over the 10-period horizon. The proportion of variance explained by oil price is relatively high compared to other variables in the model. The magnitude of its impact increases from 21% in the first period to over 30% in the second to the fifth period. It, however, drops marginally from approximately 31% in the fifth period to approximately 28% in the tenth period. Oil price, on average, accounts for approximately 30% of the variation in carbon emissions over the 10-period horizon.

Lastly, the proportion of variance explained by urbanization is negligible over the 10-period horizon. Its magnitude drops from approximately 2% in the first period to approximately 0.5% in the tenth period. On average, urbanization accounts for approximately 0.6% of the variation in carbon emissions over the 10-period horizon. Considering the fact that the estimated results can be sensitive to the ordering of the variables in the model; we rearrange the sequence by placing the first variable last and the last variable first to ascertain the robustness of our model. The results obtained are not significantly different from the one reported in the study. However, the magnitude of carbon emissions own shock increases when Co2 is arranged as the first variable.

**Table 10**

Decomposition of Variance Error of Co2 from VECM

| | Explained by Innovation | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Period** | **SE** | **$fdi^-$** | **$fdi^+$** | **top** | **pci** | **cpp** | **oip** | **urb** | **Co2** |
| 1 | 0.16928 | 0.674 | 1.465 | 1.625 | 8.978 | 0.300 | 21.455 | 1.760 | 63.743 |
| 2 | 0.25231 | 0.481 | 2.148 | 1.465 | 4.277 | 0.245 | 36.766 | 0.800 | 53.817 |
| 3 | 0.32421 | 0.377 | 2.481 | 5.561 | 4.748 | 1.142 | 35.158 | 0.512 | 50.021 |
| 4 | 0.37723 | 0.389 | 4.613 | 5.452 | 7.274 | 2.088 | 33.073 | 0.449 | 46.663 |
| 5 | 0.44019 | 0.457 | 7.196 | 5.224 | 8.238 | 2.708 | 30.610 | 0.344 | 45.223 |
| 6 | 0.49155 | 0.472 | 7.197 | 4.795 | 9.381 | 3.741 | 29.335 | 0.291 | 44.788 |
| 7 | 0.53043 | 0.424 | 6.723 | 4.602 | 11.039 | 4.521 | 28.982 | 0.338 | 43.372 |
| 8 | 0.56057 | 0.390 | 6.576 | 4.787 | 12.466 | 5.196 | 28.318 | 0.408 | 41.659 |
| 9 | 0.58666 | 0.378 | 6.583 | 4.910 | 13.134 | 5.940 | 27.793 | 0.473 | 40.788 |
| 10 | 0.61161 | 0.393 | 6.614 | 4.869 | 13.407 | 6.470 | 27.610 | 0.515 | 40.122 |

Notes: The table presents decomposition of the variance error from carbon emissions. The VDCs measure the relative contribution of each random (one-standard deviation) shock to the endogenous variables in the VECM. Ordering: $fdi^-$, $fdi^+$ top, pci, cpp, oil urb, co2.

Finally, we investigate the direction of causation among the variables based on the VEC model. Table 11 shows the results of the causality test. First, there is evidence of unidirectional causality running from carbon emissions to a positive change in foreign direct investment and not otherwise. Secondly, the ratio of private sector credit to GDP and oil prices have predictive power on trade openness. Thirdly, positive changes in foreign direct investment Granger-cause both oil prices and the ratio of private sector credit to GDP. Moreover, the causality test shows that there is unidirectional causality from carbon emissions to urbanization.

**Table 11**

Block Exogeneity Wald Test

| | **CO2** | ***fdi-*** | ***top*** | ***pci*** | ***cpp*** | ***oip*** | ***urb*** | **joint** | |
|---|---|---|---|---|---|---|---|---|---|
| *CO2* | ----- | 1.138 | 0.708 | 1.643 | 5.139 | 2.785 | 4.355 | 3.907 | 15.444 |
| *$fdi^-$* | 1.641 | ----- | 1.607 | 0.325 | 2.278 | 3.617 | 1.450 | 0.554 | 7.600 |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| *fdi*+- | 9.963*** | 0.635 | ------ | 3.659 | 2.069 | 1.653 | 3.024 | 2.418 | 18.249 |
| *top* | 4.395 | 0.228 | 2.869 | ---- | 2.750 | 5.524* | 9.648*** | 1.248 | 18.632 |
| *pci* | 0.004 | 0.295 | 6.880** | 2.270 | ---- | 0.705 | 0.843 | 0.387 | 15.042 |
| *cpp* | 0.991 | 0.551 | 10.806*** | 3.483 | ----- | 2.331 | 0.507 | 0.069 | 16.107 |
| oip | 0.078 | 0.346 | 5.180* | 3.766 | 1.463 | 0.940 | ------ | 0.715 | 9.169 |
| urb | 10.979*** | 1.508 | 0.886 | 0.615 | 0.560 | 2.312 | 0.203 | --- | 25.446** |

Notes: The table presents the results block exogeneity test to ascertain the direction of causation among the variables based on vector error correction model. *, ** and *** denote significance levels for 10%, 5% and 1%, respectively.

## 5. Conclusion

The objectives of the paper are to firstly, ascertain whether foreign direct investment and carbon emissions are cointegrated; secondly, examine whether the association between the two phenomena is asymmetric or not; thirdly, estimate the effect of foreign direct investment on carbon emissions; and lastly, examine the direction of causation between foreign direct investment and carbon emissions in Nigeria. The paper employs nonlinear ARDL, VECM, and Granger causality approaches to achieve the above-stated objectives over 1980-2022. The results show that carbon emissions, foreign direct investment, energy use, urbanization, per capita income, the ratio of private sector's credit to GDP, and oil prices are cointegrated, thus confirming the first objective of our study. The results equally confirm the short run asymmetric relationship between carbon emissions and foreign direct investment, which suggests that carbon emissions respond differently to changes in foreign direct investment in the short run. This finding provides evidence on the second objective of this study. The results reveal that both negative and positive changes in foreign direct investment reduce carbon emissions in Nigeria. However, compared to positive movement in foreign direct investment, negative reduction in foreign direct investment produces a much more significant and stronger impact on carbon emissions in Nigeria. This finding provides clear evidence on the third objective of our work. Furthermore, the results show that trade openness helps to reduce carbon emissions both in the long and short run. Also, the ratio of the private sector's credit to GDP lagged one period enhances environmental quality as it reduces carbon emissions. The results equally reveal that energy use assists in reducing carbon emissions, especially in the short run but increases it in the long run. The results show that per capita income increases carbon emissions in Nigeria, thus supporting the 'affluence effect' hypothesis. Urbanization increases carbon emissions in the short run but reduces them in the long run, thus supporting the ecological modernization theory. Finally, our results confirm unidirectional causality from carbon emissions to positive change in foreign direct investment in Nigeria, thus providing evidence on the fourth objective of this work.

The implications of the findings are that firstly, policymakers need to consider nonlinearity in analyzing the link between carbon emissions and foreign direct investment. Secondly, the policy of trade liberalization needs to be pursued vigorously, as trade openness reduces carbon emissions. However, this must be accompanied by strict enforcement of all environmental regulations designed to control carbon emissions. Thirdly, there is a need for policymakers to promote the development of the financial sector. In particular, efforts must be geared towards making more credit available to the private sector to enable them to procure environmentally friendly equipment that will help reduce carbon emissions. This is particularly important considering the fact that increased economic activities tend to hurt the environment. Policymakers must promote the adoption of low-carbon emissions technologies that will facilitate the attainment of the same or even higher output level with lower carbon emissions in the long run.

This current study has examined the nexus between foreign direct investment and carbon emissions in Nigeria. However, the study has some limitations derived from the existence of institutional factors that could affect the nexus between foreign direct investment and carbon emissions that have not been considered. Moreover, the study focusses only on aggregate foreign direct investment without considering sectoral foreign direct investment.

From the study carried out and the limitations noted above, we derive some potential areas of future research to understand the links between foreign direct investment with carbon emissions. It may be interesting to introduce institutional quality variables as alternative to those used in our study. Also, there is the need to extend the research to both developed and developing countries to make comparative assessments. Finally, it may be interesting to see whether the decomposition of foreign direct investment into sectors would make any difference to the results obtained using aggregate fdi as reported in our study.

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