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Lending Rate and Carbon Emissions Nexus: Evidence from the United States of America



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ABSTRACT

Being a threat to sustainable development, pollution has attracted the attention of major policymakers and researchers. This explains the growing interest shown by researchers in the energy economics debate, which is not without inconsistencies. Our objectives in this paper therefore are, to investigate the impact of lending rate on pollution, and to determine whether the relationship between them is linear. Standard Econometric techniques, Dynamic OLS, and Markov Regime-Switching method were applied to analyze annual data of the United States of America. We contribute to the literature by being the first, to the best of our knowledge, to undertake such a study. The results seem to suggest that firstly, Lending rate Granger causes pollution, and secondly, the impact of Lending rate on pollution depends on prevailing economic and socio-political conditions. Policymakers can rely on the lending interest rate, together with prevailing economic and socio-political conditions, for purposes of initiating actions that will help reduce pollution.

1. Introduction

Pollution and climate change lead to adverse consequences that would spare no living organism be it humankind, plant or animal. It is estimated that up to ten percent (10%) of global income is likely to be lost for every unit increment in temperature (Taghvaei, Aloo, & Shirazi, 2016). This might explain why economists, environmentalists, sustainability advocates, international organizations and world leaders, have all urged for caution aimed at reducing pollution and environmental degradation. In the banking sector, adoption of the equator principle is geared towards responsible financing, so that banks' operations are not inimical to the environment (Finger, Gavius, & Manos, 2018; Shahbaz, van Hoang, Mahalik, & Roubaud, 2017).

Spurred by the need for finding solutions to the pollution menace, academicians and economists have spent a lot of time and efforts, researching into the body of knowledge in energy economics. Theoretically, it is believed that as economies grow, the fear of environmental damage becomes a major concern of many. This fear is based on the principle that increase in production, leads to the generation of more emissions and waste (Grossman, 1995). Xiong, Tu, and Ju (2017)

support this view when they state that, the major concern for emerging economies during the economic development process, is environmental degradation.

Another school of thought postulates that economic and financial development lead to an improved environment. According to the proponents of this theory, individuals and firms benefiting from increased output and financial development would have easy access to funds, and therefore secure the best equipment and technology, making their operations less harmful to the environment. When interest rate falls for example, labour intensive firms will have access to credit enabling them to acquire capital intensive technologies. In this respect Rybczynski Theorem explains that labour intensive industries will shift towards capital-oriented industries, if the labour market is competitive. The volume of production of capital-oriented industries will increase exponentially and the rate of pollution will rise tremendously leading to deterioration of environmental quality. Therefore, we can assume that lending rate fluctuation impact on financial development through industrial revolution that could influence a country's economic growth. There is also the Environmental Kuznets Curve (EKC) hypothesis which postulates that the relationship between development and carbon emissions, follow an inverted u-shaped path.

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Similar to what exists in theory, empirical studies too are not without controversies. For example, [Katircioğlu and Taşpınar \(2017\)](#) found a long-run relationship between financial development and EKC, whereas the work of [Taghvaei et al. \(2016\)](#) did not seem to find such a relationship in the long-run. Besides the controversies both in theory and in empirical studies, the lack of inquiry into how Lending interest rate impact on environmental quality, is an obvious gap in literature that need to be investigated. We take a cue from the work of [Zaman \(2012\)](#) who alluded to the fact that among other factors, financial capability play a major role in how ethical manufacturing firms in Malaysia, behave towards the environment. Being the main source of financing to firms and households, banks' Lending interest rates have consequences on how users of these financing, undertake environmental management practices. Our argument should be viewed in the context of the imposition of additional cost to citizens and firms when Lending rates rise. If we are to follow the findings of [Zaman \(2012\)](#) therefore, an increase in Lending rate will have repercussions for environmental quality. Hence this study is focused on investigating the question of whether Lending rate does affect pollution in US. We have chosen to study the US for two reasons;

- I. base on the report published by Environmental Protection Agency (EPA)¹, the U.S. is responsible for 15% of global carbon dioxide emissions.
- II. The US has the biggest economy in the world, and possesses a developed financial sector.

The results indicate that lending rate and carbon emissions in the U.S. are positively correlated over the period under consideration. Thus both variables move together in the same direction with a correlation value of 0.4 ([Table 3](#)). [Figs. 1 and 2](#) reveal the pictorial similarities in the dynamics of both variables. Though unpredictable, carbon emissions and lending rate in the U.S. move towards their lowest values from 1968 towards 2014. In 1968, about 19.1 metric tons per capita of carbon emissions was recorded. Emissions was at its peak in 1973 with a recorded value of 22.5, and in 2012, it had reached its lowest at 16.3 metric tons per capita. There is an indication, however that carbon emissions were beginning to rise again from 2013. A similar picture is indicative of the trend in U. S. lending rate over the period. The rate was 6.3% in 1968, rose to its highest in 1981 with a value of 18.9 before settling at its lowest at 3.3 in 2009. Thereafter, it remained constant at its lowest for six consecutive years up to 2014. Despite lending rate remaining constant over the period 2009–2014, carbon emissions continue its fluctuating trend. Such a phenomenon is suggestive for enquiry into the lending rate-carbon emissions nexus.

There are four main objectives in this study namely;

- a. To investigate the existence of a theoretical causal relationship between Lending rate and pollution.
- b. Estimate the impact of Lending rate on pollution,
- c. To determine whether the relationship between Lending rate and pollution is linear and
- d. To check whether growth, financial development, and energy consumption moderate the relationship between lending rate and carbon dioxide emission.

In pursuing these objectives, we analyzed data from the United States of America over the period 1968–2014, using Standard Econometric techniques, Dynamic OLS, and Markov Regime-Switching technique. The main findings from our analysis are listed below;

1. Granger causality is from Lending rate to pollution.

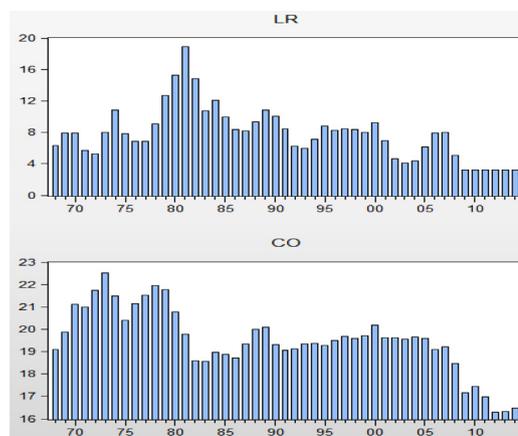


Fig. 1. Bar chart of Carbon emissions and Lending rate in the U.S. for the period 1968–2014 Source: Generated from EViews software.

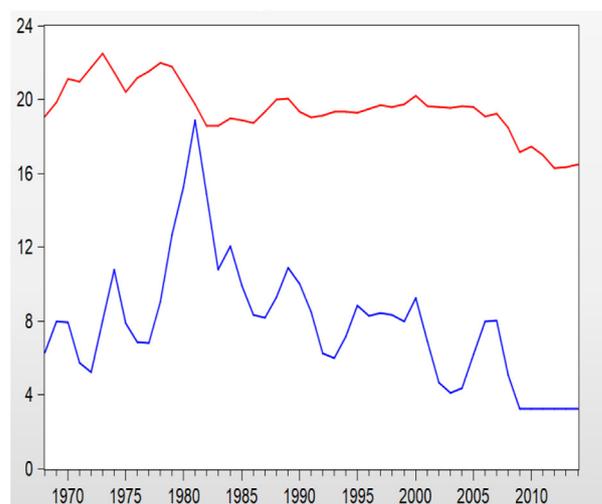


Fig. 2. Line graph of Carbon emissions and Lending rate in the U.S. for the period 1968–2014 Source: Generated from EViews software.

2. Lending rate reduces pollution under stable economic conditions but increases pollution during crisis and unstable periods.
3. Financial development, energy consumption, and growth simultaneously moderate in the Lending rate-Carbon emissions relationship, only under sound socio-economic and political conditions.

We contribute to the body of knowledge by being the first, to the best of our knowledge, to study the relationship between Lending rate and pollution, in the energy economics debate. We further extend the debate by investigating the moderating role of the main energy economics variables including growth, financial development, and energy consumption in the relationship, and by employing a Markov Regime-Switching technique which is an advanced method of estimations.

The rest of the paper is organized as follows; [Section 2](#) provides a review of relevant literature, [Section 3](#) presents the methodology. Data and empirical results are provided in [Section 4](#), the results are discussed in [Section 5](#), and finally, conclusion and policy implications constitute [Section 6](#).

2. Literature review

2.1. Theoretical review

Both industrialization and economic development have generally been linked to a deterioration of the environment, due to an increased

¹ Retrieved from <https://www.epa.gov/ghgemissions/overview-greenhouse-gases>

usage of energy and burning of fossil fuel. The resultant effect is the discharge of greenhouse gases and other pollutants into the atmosphere. In emerging economies that need substantial amounts of FDI inflows to support growth, environmental degradation is a major concern (Geddes, Schmidt, & Steffen, 2018).

But some have argued that financial development that result from economic growth, provides resources and advanced technology ensuring that, manufacturing and energy usage do not cause excessive pollution (Wesseh & Lin, 2018; Zaidi, Zafar, Shahbaz, & Hou, 2019). According to this theory, firms will have adequate and accessible funding from financial institutions which would allow them to acquire the right technology and machinery, that are environmentally friendly.

There is also the EKC hypothesis which postulates an inverted u-shaped path describing the impact of development on carbon dioxide emissions (Hanif, Raza, Gago-de-Santos, & Abbas, 2019; Lau, Choong, & Eng, 2014). This theory suggests that early stages of developments increase pollution, but there exist a turning point after which further development improves environmental quality. Since these theories are conflicting, empirical findings might provide a clearer picture regarding the relationship between development and pollution.

2.2. Empirical review

Sustainability considerations have necessitated the conduct of many empirical works in the field of energy economics. For effective and efficient policymaking, it is important to establish the existence of a long-run relationship between variables. In this regard, Gokmenoglu, Ozatac, and Eren (2015), Taghvaei et al. (2016), Katircioğlu and Taşpinar (2017), and Nasreen, Anwar, and Ozturk (2017) are papers worthy of consideration.

A study of the relationship between financial development and pollution in Turkey for the period 1972–2012, shows a unidirectional causality from financial development to CO₂ emissions (Gokmenoglu et al., 2015). Using data from 1960 to 2010 also from Turkey, Katircioğlu and Taşpinar (2017) were interested in investigating the moderating role of financial development in the EKC. Their results provide suggestions for a long-term equilibrium relationship between financial development and the EKC. In addition, they indicate that financial development moderates the impact of real output on CO₂ emissions. They find this impact to be negative in the short-run, and positive in the long-run. Deviating from other studies, Nasreen et al. (2017) were interested in how financial stability affect environmental quality. After analyzing data of South-Asian countries from 1980 to 2012, they report the existence of unidirectional relationship from financial stability to CO₂ emissions. According to the authors, stability in the financial sector improves environmental quality. On the contrary, Taghvaei et al. (2016) do not seem to establish a strong long-run relationship between financial development and CO₂ emissions in their study of Iran, using data from 1974 to 2012. They indicate further that financial development is negatively related to CO₂ emissions, though not significant in the long-run. The relationship, however, is significantly positive in the short-run.

Without giving much attention to the direction of causality, the following empirical works provide a sense of how changes in certain variables impact on environmental pollution. A study of China with data spanning 1953–2006, reports of a negative relationship between financial development and CO₂ emissions (Jalil & Feridun, 2011), an implication of improvement in the environment with increasing financial sector development. Again in China, Xiong et al. (2017) employ a panel data of 30 provinces from 1997 to 2011. They report a negative impact of financial development on CO₂ emissions only in the developed regions of China. In less developed regions, however, the impact is positive.

Lastly, studies conducted on firms with regards to this body of knowledge are considered. The equator principles were instituted to

ensure that financial institutions undertake environmental impact assessment on their clients before extending financing to same. This action is necessary in the context of building a culture of sustainability practices in organizations. According to Finger et al. (2018), financial institutions in developed countries that adopted the Equator Principles, experienced increases both in funding activities and share of interest income. Those institutions in developing countries that adopted the Equator Principles, on the other hand, realized a decrease in funding activities and share of interest income. Their research covered some 78 banks in 34 countries globally, from 2003 to 2015. Zaman (2012) studied 150 manufacturing companies in Malaysia with primary data. The results of the regression analysis indicate that among other factors, the financial capabilities of firms are able to explain their Environmental Ethical Commitment.

Controversies exist in findings as per the literature reviewed above. For this reason, more work is required in this body of knowledge. For instance, the study carried out by Zaman (2012) indicates that firms' commitment to ethical environmental practices depends partly on the availability of funds. Since firms largely rely on banks for short to medium-term financing, there is a greater likelihood of Lending rate becoming a barrier for firms to access funding from banks. Consequently, the Lending rate should impact on environmental pollution directly or otherwise. Hence the relation between Lending rate and environmental pollution is a gap which has not received much attention in the energy economics literature.

3. Methodology

It is hoped that this study would be useful for policymaking. For this reason, standard econometric techniques have been employed for analysis. The usual procedure is to determine the stationarity of the main variables, the order of lag for Vector autoregression (VAR), and finally leading to the determination of whether cointegration exists among the variables. Even at this point, regression is performed only after a determination is made with regards to the exogeneity/endogeneity of variables. In the end, a lead-lag relationship is obtained for further analysis. In a nutshell, it is the data's nature that determines whether a variable is dependent or independent.

For the cointegration test, all variables must be non-stationary in their level forms. This is important because only non-stationary variables possess theoretical information. It is also expected that, in their first differenced forms, the variables should be stationary especially, if the cointegration test involves the use of Engle-Granger or Johansen techniques. Preference is given to Augmented Dicky-Fuller (ADF) technique for determining stationarity among the several techniques available, as it takes care of error term serial correlation (Shahbaz, Omay, & Roubaud, 2018).

Once the stationarity test has been performed, and the order of lag determined using VAR, all is set for conducting cointegration test. The two techniques used to determine cointegration are Engle-Granger and Johansen. Engle-Granger is based on the principle of determining cointegration by testing the stationarity of the error term. Below is a representation of the equation for determining the stationarity of the error term;

$$\Delta_t = \beta_1 + \beta_2t + \delta Y_{t-1} + \sum \alpha_i \Delta Y_{t-1} + \Delta_t$$

where ε_t is the white noise of the error term, $\Delta Y_{t-1} = Y_{t-1} - Y_{t-2}$, and $\Delta Y_{t-2} = Y_{t-2} - Y_{t-3}$. Stationarity is obtained if δ is statistically equal to zero (0). This implies that the t-statistic for Y_{t-1} would be less than the critical value of the estimation. Johansen technique, on the other hand, assigns hypothetical coefficients to the variables in a manner that makes the error term stationary. It has two advantages over the Engle-Granger technique. Firstly, it provides the certainty of cointegration. Secondly, it has the capacity to observe the existence of more than one cointegration in the system.

The next important step is to determine which variable is exogenous (strong) or endogenous (weak). This determination is made using the Vector Error Correction Model (VECM). In this process, at least one variable should be found to be endogenous. Since the determination at this stage is absolute endogeneity and exogeneity, it is possible to have more than one variables being endogenous or exogenous. Hence resulting in the need for determining relative exogeneity or endogeneity.

To complement the VECM, Variance Decomposition (VDC) technique is employed to determine the relative exogeneity or endogeneity of variables. Through the VDC, the direction of Granger causality is obtained. It is only at this stage, one can conclusively identify which variable is dependent or independent. The VDC technique is based on the principle that the forecast error term of a variable is decomposed into proportions of shocks attributed to all variables including itself. A variable's relative strength is determined by the proportion of its variance that is explained by its own past innovations. If the highest proportion of its variance depends on its own past shocks, then it is the most exogenous (strongest) variable. VDC makes it possible to measure the proportion of dependence of variances of variables on their own past innovations. In this way, the variables are arranged from the strongest to the weakest.

Since with certainty, it is established as to which variable is dependent (endogenous), a dynamic OLS regression is performed for the determination of regression coefficients and variance (Omay, Shahbaz, & Hasanov, 2020). We then proceed to perform a Markov Regime-Switching technique, which allows regression coefficients and variance to be state or regime dependent (Reboredo, 2010). Examples of regimes include economic growth or recession, financial stability or crisis, state of peace or conflict, and political stability or upheavals. Such results provide implications for policymaking.

4. Data and empirical results

4.1. Data

This paper aims at studying the impact of Lending rate on carbon emissions. From literature, the most recurring variables in this body of knowledge include Carbon dioxide emissions (CO₂), financial development (FD), energy consumption (EN), and growth (Y). Together with the Lending rate (LR), these constitute the five main variables in this study. Based on the EKC hypothesis (Nasreen et al., 2017), the variable Y² has been given some attention. Besides these primary variables, three interaction variables formed through LR*FD, LR*EN, and LR*Y have been utilized in the analysis. Also in consistent with literature, trade volume (TV), urban population (UP), population density (PD), and labor force (LF) have been adopted as control variables. The annual data has been taken from the United States of America (USA) covering 1968 to 2014, and obtained from World Development Indicators (WDI) of the World Bank. A summary of definitions and nature of the variables, is shown in Table 1.

Table 1
Variables and their definitions.

| Variable | Representation | Proxy | Unit of measurement |
|-----------------------|-----------------|---|---------------------------------|
| Carbon Emissions | CO ₂ | CO ₂ emissions | Metric tons per capita |
| Lending Rate | LR | Lending interest rate | % |
| Financial Development | FD | Domestic credit to the private sector by banks | % of GDP |
| Energy Consumption | EN | Energy use | kg of oil equivalent per capita |
| Economic Growth | Y | GDP | Constant of 2010 US\$ |
| Trade Volume | TV | Trade | % of GDP |
| Urban Population | UP | Population in urban agglomerations of more than 1 million | % of the total population |
| Population Density | PD | Population density | People per sq. km of land area |
| Labour Force | LF | Labor force participation rate, total | % of total population ages 15+ |

Ultimately, this study wishes to estimate coefficients that would provide an indication of the impact of LR in the energy economics nexus. Two regression models are to be estimated in this study. The first model has as regressors, the main independent variables. In the second model, interaction variables are added to the main variables as regressors. Below are the two model specifications;

$$LCO_2 = \beta_0 + \beta_1 LCO_2(-1) + \beta_2 LLR + \beta_3 LFD + \beta_4 LEN + \beta_5 LY + \Theta_1 K_i + \varepsilon_t \tag{1}$$

$$LCO_2 = \beta_0 + \beta_1 LCO_2(-1) + \beta_2 LLR + \beta_3 LFD + \beta_4 LEN + \beta_5 LY + \beta_6 FD * LR + \beta_7 EN * LR + \beta_8 LY * LR + \Theta_1 K_i + \varepsilon_t \tag{2}$$

where LCO₂, LLR, LFD, LEN, and LY are natural logarithms of CO₂, LR, FD, EN, and Y respectively. FDLR, ENLR, and LYLR, are interaction variables formed from the combinations LFD*LLR, LEN*LLR, and LY*LLR respectively. Controls are represented by K_i, and they include DTV, DUP, DPD, and DLF, which are respectively, the first-differenced forms of TV, UP, PD, and LF. B₀, B₁, B₂, B₃, B₄, B₅, B₆, B₇, B₈, and Θ are coefficients to be estimated. ε_t represents white noise.

It is worth noting that for determining cointegration, only the five main variables were used. They include CO₂, LR, FD, EN, and Y. Due to collinearity, both Y and Y² are unable to feature in the same regression. Hence, where necessary they have been made to appear one at a time during estimations.

4.2. Empirical results

Descriptive statistics and correlation matrix of the main variables are presented in Tables 2 and 3 respectively. Except for the correlation between CO₂ and EN which seem to be high with a value of 0.87, the rest appear normal. If both CO₂ and EN are independent variables in the same regression, issues of co-linearity will arise (Janmaat, Ban, & Boesch, 2013). It is also observed that Y has a negative correlation with all the other variables.

Since only non-stationary variables possess theoretical information, it is prudent to ensure that our main variables intended for determining cointegration among them, are non-stationary. A further requirement if Engel Granger or Johansen technique will be utilized for cointegration test is for variables to be non-stationary or I(1) in their level forms, and stationary or I(0) in their differenced forms.

Results of unit root tests are shown in Tables 4 and 5 for level and differenced form variables respectively. The null hypothesis for this test is, that variables are non-stationary. In the event that the t-statistic is lower than the ADF critical value, the null is upheld, and the variable concerned is regarded as non-stationary. Conversely, a rejection of the null, produces a t-statistic higher than the critical value. In that case, the variable is regarded as stationary. The results show that all the variables are non-stationary in their level forms, but stationary in their first differenced forms.

Ideally, the next step in the standard econometric procedure should have been to determine the number of lags in the VAR, followed by Engel-Granger cointegration technique. However, these could not be

Table 2
Descriptive Statistics.

| Variable | CO ₂ | LR | FD | EN | Y |
|--------------------|-----------------|----------|----------|----------|----------|
| Mean | 19.51226 | 7.862447 | 51.98193 | 7657.614 | 9.81E+12 |
| Standard deviation | 1.440184 | 3.318840 | 4.044854 | 374.3723 | 3.77E+12 |
| Minimum | 16.30402 | 3.250000 | 44.23576 | 6869.385 | 4.49E+12 |
| Maximum | 22.51058 | 18.87000 | 59.75453 | 8438.403 | 1.62E+13 |

Notes: CO₂, LR, FD, EN, and Y represent Carbon emissions, Lending rate, Financial development, and GDP respectively.

Table 3
Correlation between Variables.

| Variable | CO ₂ | LR | FD | EN | Y |
|-----------------|-----------------|-------|-------|-------|-------|
| CO ₂ | 1.00 | 0.40 | 0.28 | 0.87 | -0.69 |
| LR | 0.40 | 1.00 | 0.21 | 0.33 | -0.55 |
| FD | 0.28 | 0.21 | 1.00 | 0.23 | -0.13 |
| EN | 0.87 | 0.33 | 0.23 | 1.00 | -0.34 |
| Y | -0.69 | -0.55 | -0.13 | -0.34 | 1.00 |

Notes: CO₂, LR, FD, EN, and Y represent Carbon emissions, Lending rate, Financial development, Energy consumption, and GDP respectively

Table 4
ADF Unit Root test for Level form variables.

| Variable | Test Statistics | Critical Value | Results |
|------------------|-----------------|----------------|----------------|
| LCO ₂ | -2.4556 | -3.5217 | Non-stationary |
| LLR | -2.4435 | -3.5217 | Non-stationary |
| LFD | -2.8780 | -3.5217 | Non-stationary |
| LEN | -2.3897 | -3.5217 | Non-stationary |
| LY | -1.4799 | -3.5217 | Non-stationary |

Notes: LCO₂, LLR, LFD, LEN, and LY are logarithms of CO₂, LR, FD, EN, and Y respectively.

Table 5
ADF Unit Root test for Differenced Form Variable.

| Variable | Test Statistics | Critical Value | Results |
|------------------|-----------------|----------------|------------|
| DCO ₂ | -5.0312 | -2.9358 | Stationary |
| DLR | -5.9120 | -2.9358 | Stationary |
| DFD | -3.6258 | -2.9358 | Stationary |
| DEN | -4.7881 | -2.9358 | Stationary |
| DY | -4.2000 | -2.9358 | Stationary |

Notes: DCO₂, DLR, DFD, DEN, and DY are first-differenced forms of CO₂, LR, FD, EN, and Y respectively.

performed due to the presence of collinearity existing between CO₂ and EN. As a result, Johanssen technique was resorted to, in testing for the existence of cointegration (Dionisio, Menezes, & Mendes, 2007) among the key variables.

Presented in Tables 6a and 6b are cointegration results based on Maximal Eigenvalue and Trace of the Stochastic Matrix respectively. Because the Johansen method is capable of identifying the existence of more than one cointegration, the null hypothesis is not fixed. At the initial stage, a null of no cointegration, with an alternative hypothesis of the existence of one cointegration suffices. In case the initial null hypothesis is rejected, the next null of one cointegration, with an alternative of two cointegrations, is then considered. This process is followed until a point where the null holds, and the number of cointegrations in the system is arrived at. Rejection of the null is based on the t-statistic being lower than any of the critical values of either 90% or 95% confidence level. In Table 6a, the null of no cointegration is rejected as the t-statistic (44.7514) is higher than both critical values. Hence the test is moved to the next level where the null of one cointegration is upheld, because the t-statistic (16.1519) is lower than both critical values. Table 6b provides results that support what is obtained

Table 6a
Johansen Cointegration with VAR of 1 based on Maximal Eigenvalue of the Stochastic Matrix.

| Null value | Alternative | Statistics | 95% CV | 90% CV |
|------------|-------------|------------|---------|---------|
| r = 0 | r = 1 | 44.7514 | 37.8600 | 35.0400 |
| r ≤ 1 | r = 2 | 16.1519 | 31.7900 | 29.1300 |

Table 6b
Johansen Cointegration with VAR of 1 based on Trace of the Stochastic Matrix.

| Null value | Alternative | Statistics | 95% CV | 90% CV |
|------------|-------------|------------|---------|---------|
| r = 0 | r ≥ 1 | 83.0514 | 87.1700 | 82.8800 |
| r ≤ 1 | r ≥ 2 | 38.3000 | 63.0000 | 59.1600 |

Notes: The statistics refer to Johansen-Juselius's log-likelihood maximal eigenvalue and trace statistics. A number of cointegrating vectors are represented by r.

from 6a. Both tables are conclusive on the existence of only one cointegration among the variables.

Despite knowing the variables have a long-run relationship, it is unclear which ones are endogenous or exogenous. Table 7 contains the results of the VECM for detecting the endogeneity/exogeneity of variables. The null hypothesis for this techniques assumes that variables are exogenous. Thus the coefficient of the error correction term (Ecm1(-1)) is the focal point for this determination. Below is the regression considered in the VECM:

$$y = C + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \beta_4 X_4 + \beta_5 \varepsilon_{t-1}$$

where ε_{t-1} is the error correction term.

Prior to determining whether a variable is exogenous or not, each is made to take the position of y while the rest occupy the places of X₁, X₂, X₃, and X₄ in turns. Any variable that represents y, and β_5 is found to be statistically significant at a level below 5%, that variable is considered endogenous. Otherwise, it is exogenous.

According to results in Table 7, three variables namely CO₂, EN, and Y are endogenous. LR and FD were found to be exogenous. Establishing the chain of Granger Causality requires further analysis to obtain the variables' relative exogeneity.

In Table 8, the results of VDC which determines relative exogeneity of variables, are provided. According to this technique, the most exogenous variable is one whose variance depends most on its own past innovations, compared with its dependence on those of other vari-

Table 7
Vector error correction estimates for variables.

| Ecm1(-1) | Coefficient | T-Ratio(Prob) | CV | Results |
|------------------|-------------|------------------|----|------------|
| DCO ₂ | -0.0622 | 7.2554[0.000]*** | 5% | Endogenous |
| DLR | -0.2207 | 2.4961[0.016]** | 5% | Exogenous |
| DFD | -0.0270 | 1.7955[0.079]* | 5% | Exogenous |
| DEN | -0.0511 | 6.5321[0.000]*** | 5% | Endogenous |
| DY | -0.0267 | 3.5416[0.001]*** | 5% | Endogenous |

Notes: 1. *, **, *** represent significant level at 10%, 5% and 1% respectively.

Table 8
Variance decomposition estimates (Generalised).

| | Horizon | LCO | LLR | LFD | LEN | LGDP | TOTAL | SELF-DEP | RANKING |
|------------------|---------|-------------|-------------|-------------|-------------|-------------|-------|----------|---------|
| LCO ₂ | 3 | 26.8 | 16.5 | 3.9 | 32.2 | 20.6 | 100 | 28.6 | 5 |
| LLR | 3 | 0.1 | 82.2 | 8.1 | 0.1 | 9.5 | 100 | 82.2 | 1 |
| LFD | 3 | 12.8 | 2.2 | 54.9 | 12.8 | 17.3 | 100 | 54.9 | 2 |
| LEN | 3 | 22.6 | 14.8 | 3.3 | 37.6 | 21.7 | 100 | 37.6 | 4 |
| LGDP | 3 | 19.3 | 1.5 | 8.7 | 25.6 | 44.9 | 100 | 44.9 | 3 |
| | Horizon | LCO | LLR | LFD | LEN | LGDP | TOTAL | SELF-DEP | RANKING |
| LCO ₂ | 6 | 21.7 | 25.9 | 2.4 | 30.4 | 19.6 | 100 | 21.7 | 5 |
| LLR | 6 | 0.2 | 79.4 | 8.0 | 0.2 | 12.2 | 100 | 79.4 | 1 |
| LFD | 6 | 12.5 | 1.3 | 54.7 | 13.4 | 18.1 | 100 | 54.7 | 2 |
| LEN | 6 | 18.5 | 23.2 | 2.0 | 35.6 | 20.7 | 100 | 35.6 | 4 |
| LGDP | 6 | 18.0 | 2.6 | 7.5 | 26.2 | 45.7 | 100 | 45.7 | 3 |
| | Horizon | LCO | LLR | LFD | LEN | LGDP | TOTAL | SELF-DEP | RANKING |
| LCO ₂ | 9 | 19.5 | 30.1 | 1.7 | 29.5 | 19.1 | 100 | 19.5 | 5 |
| LLR | 9 | 0.3 | 77.6 | 7.9 | 0.2 | 13.9 | 100 | 77.6 | 1 |
| LFD | 9 | 12.4 | 0.9 | 54.5 | 13.7 | 18.5 | 100 | 54.5 | 2 |
| LEN | 9 | 16.7 | 27.0 | 1.5 | 34.6 | 20.2 | 100 | 34.6 | 4 |
| LGDP | 9 | 17.3 | 3.3 | 6.9 | 26.5 | 46.1 | 100 | 46.1 | 3 |

ables. Based on 3, 6, and 9 years horizons, the results show that LR is the most exogenous (strongest), followed by FD, Y, EN, and CO₂ in that order. Being the weakest, the results imply that CO₂ is the dependent variable, whilst the rest are independent. As shown in Fig. 3, LR Granger causes FD which in turn causes Y. Then Y causes EN, which ultimately Granger-causes CO₂.

Provided in Table 9 are regression results of the dynamic OLS. Columns 1 to 4 are results where the interaction variables are not part of the regression. In columns 5 to 8, interaction variables are included in the regressions. From column 1–4, the results indicate a significantly negative relationship between LR and CO₂. On average, the indication is that, for a 1% increase in LR, CO₂ emissions fall by 0.02%. On the contrary, the relationship between them becomes positive when the interaction variables are included in the regressions (columns 5–7). In column 8 where all controls are included alongside the interaction variables however, the relationship becomes negative and insignificant.

Furthermore results from column 8 show that FDLR and ENLR have no significant impact on CO₂. However, LYLR exhibits a significantly positive association with CO₂ emissions. For FD, EN, and Y to act as moderators in the relationship between LR and CO₂, the interaction variables must have significant impacts (Katircioğlu & Taşpınar, 2017). Hence, Y appears to be the only moderator amongst these variables, moderating a positive relationship between LR and CO₂.

Considering the rest of the main variables, the results show an insignificant positive relationship between FD and CO₂, except in column 4 where the relationship seems to be significant. Whilst EN shows a significantly positive association with CO₂, the relationship between

Y and CO₂ is significantly negative. The results further imply that a 1% increase EN and Y would cause CO₂ to rise by 1.13%, and fall by 0.16% respectively. All control variables with the exception of PD, exhibit a significant association with CO₂. TV and UP have positive impacts on CO₂, whereas the impact from LF appears negative.

There is a need for further analysis to check whether the coefficients reported in Table 9, are constant throughout the entire period under investigation. We employed a Markov regime switching technique for this purpose, and the results hereby reported in Table 10. Two sections, A and B are found on this table. Section A consists of three columns, a normal DOLS regression with main independent variables as regressors, followed by regimes 1 and 2 of its Markov Regime-Switching technique. Section B is similar to A except that, all the interaction variables have been added as regressors, a feature not found in A.

Also note that section A is a Regime-Switching analysis of column 4 of Table 9, and section B is that of column 8. In section A, the results of both regimes are similar to that of the normal in that, both indicate a negative relationship between LR and CO₂. However, the relationship in regime 2 like that of the normal, is significant, whereas that of regime 1 is insignificant. Another difference observed, comes from the fact that whiles the normal regression indicates a reduction in CO₂ by 0.018% in response to a 1% increase in LR, regime 2 shows a reduction of only 0.013%.

Results from section B show that with the inclusion of all the interaction variables, LR and CO₂ have a negative but insignificant association in the normal column. On the contrary however, this relationship is significantly positive and negative in regimes 1 and 2 respectively. By differentiating CO₂ with respect to LLR, the overall impact of LR on CO₂ are computed. For regime 1, the overall impact is derived from the expression;

$$CO_2 = 1.416 + (0.130 * LFD) + (-0.223 * LEN) + (0.001 * LY)$$



Fig. 3. Direction of Granger causality.

Table 9
DOLS with LCO₂ as the dependent variable.

| Variable | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) |
|-----------------------|----------------------|----------------------|----------------------|----------------------|----------------------|----------------------|----------------------|----------------------|
| C | -4.110*** (0.000) | -4.110*** (0.000) | -3.910*** (0.000) | -4.522*** (0.000) | -4.450 (0.144) | -7.478*** (0.000) | -7.534*** (0.000) | -3.459 (0.188) |
| LCO ₂ (-1) | 0.215*** (0.003) | 0.215*** (0.003) | 0.308*** (0.000) | 0.252*** (0.002) | 0.226*** (0.003) | 0.312*** (0.000) | 0.312*** (0.000) | 0.306*** (0.000) |
| LLR | -0.017*** (0.008) | -0.017*** (0.008) | -0.022*** (0.001) | -0.018*** (0.007) | 0.363 (0.794) | 1.930** (0.010) | 1.957** (0.011) | -0.137 (0.910) |
| LFD | 0.017 (0.533) | 0.017 (0.533) | 0.040 (0.277) | 0.069* (0.086) | 0.096 (0.694) | 0.079 (0.714) | 0.090 (0.693) | 0.040 (0.852) |
| LEN | 0.972*** (0.000) | 0.972*** (0.000) | 0.898*** (0.000) | 1.009*** (0.000) | 1.092*** (0.000) | 1.273*** (0.000) | 1.276*** (0.000) | 1.130*** (0.000) |
| LY | -0.077*** (0.000) | | -0.074*** (0.000) | -0.085*** (0.000) | -0.113*** (0.007) | -0.072*** (0.000) | -0.072*** (0.000) | -0.157*** (0.000) |
| LY ² | | -0.038*** (0.000) | | | | | | |
| FDLR | | | | | -0.034 (0.779) | -0.023 (0.831) | -0.031 (0.796) | 0.001 (0.990) |
| ENLR | | | | | -0.093 (0.430) | -0.209** (0.034) | -0.208** (0.037) | -0.120 (0.235) |
| LYLR | | | | | 0.020 (0.344) | | | 0.040** (0.048) |
| DTV | | | 0.055* (0.077) | 0.053* (0.084) | | 0.075** (0.015) | 0.075** (0.016) | 0.077*** (0.009) |
| DUP | | | 2.512** (0.030) | 3.170*** (0.009) | | 2.347** (0.034) | 2.302** (0.046) | 2.964** (0.011) |
| DPD | | | 0.819 (0.640) | 1.028 (0.548) | | | -0.310 (0.863) | -1.832 (0.344) |
| DLF | | | | -1.231* (0.085) | | | | -1.187* (0.067) |
| Adjusted R-squared | 0.9699 | 0.9699 | 0.9744 | 0.9758 | 0.9711 | 0.9782 | 0.9776 | 0.9806 |
| Prob. (F-statistics) | (0.0000) | (0.0000) | (0.0000) | (0.0000) | (0.0000) | (0.0000) | (0.0000) | (0.0000) |

Notes: 1. *, **, and *** represent respectively significance level at 10%, 5%, and 1%.
2. DTV, DUP, DPD, and DLF are first-differenced forms of TV, UP, PD, and LF.

Table 10
Results of Markov Regime-Switching Technique with LCO₂ as Dependent Variable.

| Section Variable | (A) | | | (B) | | |
|-----------------------|----------------------|----------------------|----------------------|----------------------|----------------------|----------------------|
| | Normal | Regime 1 | Regime 2 | Normal | Regime 1 | Regime 2 |
| C | -4.522*** (0.000) | -3.297*** (0.000) | -5.930*** (0.000) | -3.459 (0.188) | -8.162*** (0.000) | 1.243*** (0.000) |
| LCO ₂ (-1) | 0.252*** (0.002) | -0.091** (0.046) | 0.088*** (0.000) | 0.306*** (0.000) | 0.349*** (0.000) | 0.794*** (0.000) |
| LLR | -0.018*** (0.006) | -0.0002 (0.803) | -0.013*** (0.000) | -0.137 (0.910) | 1.416*** (0.000) | -0.608*** (0.000) |
| LFD | 0.069* (0.086) | 0.109** (0.035) | 0.020* (0.076) | 0.040 (0.852) | -0.200*** (0.003) | 0.201*** (0.000) |
| LEN | 1.009*** (0.000) | 1.014*** (0.000) | 1.189*** (0.000) | 1.130*** (0.000) | 1.403*** (0.000) | 0.520*** (0.000) |
| LY | -0.085*** (0.000) | -0.104*** (0.000) | -0.068*** (0.000) | -0.157*** (0.000) | -0.054*** (0.000) | -0.201*** (0.000) |
| FDLR | | | | 0.001 (0.990) | 0.130*** (0.001) | -0.110*** (0.000) |
| ENLR | | | | -0.120 (0.235) | -0.223*** (0.000) | -0.109*** (0.000) |
| LYLR | | | | 0.040** (0.048) | 0.001 (0.751) | 0.067*** (0.000) |
| DTV | 0.053* (0.084) | 0.109*** (0.000) | 0.038*** (0.000) | 0.077*** (0.009) | 0.009 (0.609) | 0.210** (0.000) |
| DUP | 3.170*** (0.009) | 2.011*** (0.000) | -4.316*** (0.000) | 2.964** (0.011) | 4.479*** (0.000) | 6.231*** (0.000) |
| DPD | 1.028 (0.548) | 12.888*** (0.000) | -2.158*** (0.000) | -1.832 (0.344) | -1.430* (0.094) | -5.752*** (0.000) |
| DLF | -1.231* (0.085) | -1.670*** (0.000) | 0.033 (0.872) | -1.187* (0.067) | -0.125 (0.614) | -1.335*** (0.000) |
| Adjusted R-squared | 0.9758 | | | 0.9806 | | |
| Prob (F-statistics) | (0.0000) | | | 0.0000 | | |

Notes: 1. *, **, and *** represent respectively significance level at 10%, 5%, and 1%.
2. DTV, DUP, DPD, and DLF are first-differenced forms of TV, UP, PD, and LF.

Substituting (-0.200), (1.403), and (-0.054) for LFD, LEN and LY respectively,

$$CO_2 = 1.416 + (0.130 * -0.200) + (-0.223 * 1.403) + (0.001 * -0.054)$$

$$CO_2 = 1.416 - 0.026 - 0.313 - 0.000054 = 1.08$$

Similarly, the overall impact of LR in regime 2 is computed as shown below;

$$CO_2 = -0.608 + (-0.110 * 0.201) + (-0.109 * 0.502) + (0.067 * -0.201)$$

$$CO_2 = -0.608 - 0.02211 - 0.054718 - 0.013467 = -0.70$$

The computations above therefore show that the overall impact of Lending rate on carbon emissions when interaction variables are included in the regression are 1.08 and -0.70 in regime 1 and regime 2 respectively.

Without identifying the nature of both regimes, the results would be meaningless from the viewpoint of policymaking. For that matter, we undertake to analyze patterns displayed in Figs. 4a and 4b for regime identification with regards to section A. Regime 1 seems to have occurred during periods 1969–71, 1976–84, 1997–2000, and

2011–2014. All these are characterized by economic crisis and downturns. Hence the only alternative left in characterizing regime 2, is the opposite of regime 1, which implies the existence of sound economic conditions and growth. Through the identification process, the results of section A suggest that during good economic conditions, the negative impact of LR on CO₂ is significant. However, the impact is not significant under terrible economic conditions.

A study of Figs. 5a and 5b reveals the occurrences of regime 1 of section B during periods 1973–1974, 1978–1982, 1986–1999, 2001–2002, 2005–2008, and 2011–2014. Obviously, the periods share some similarities with regime 1 of section A. The only vivid difference between them is the inclusion of periods 1973–1974, 2001–2002, and 2005–2008, which are absent in regime 1 of section A. We, therefore, narrow our search for the character of this regime to these three periods. It is observed that in addition to economic crisis and downturns, regime 1 of section B is also characterized by outside shocks such as conflicts, political upheavals, and trade sanctions.

Other parameters of importance that can be obtained from the Regime-Switching technique are the transition probabilities. Basically, the transition probabilities give an indication of the likelihood of occurrence associated with each regime. They also provide the probability of transition from one regime to another. Table 11 shows transi-

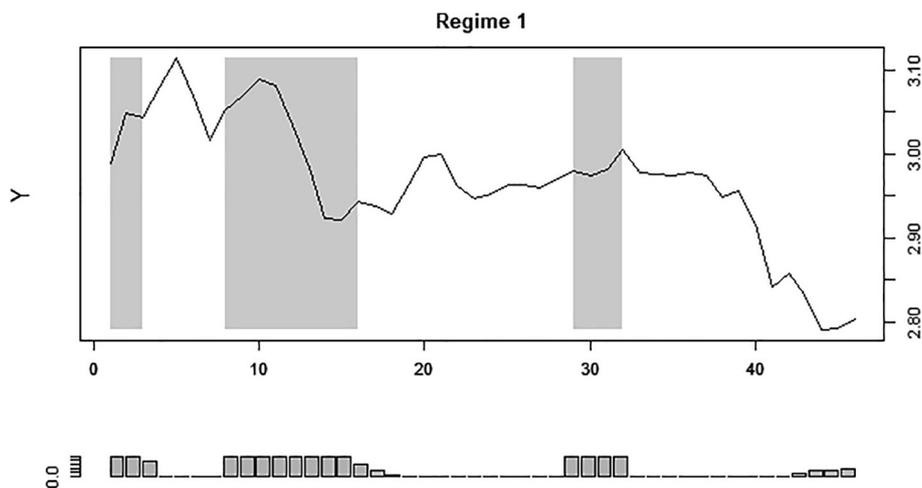


Fig. 4a. Graphical representation of Regime 1 with respect to Section A of Table 10.

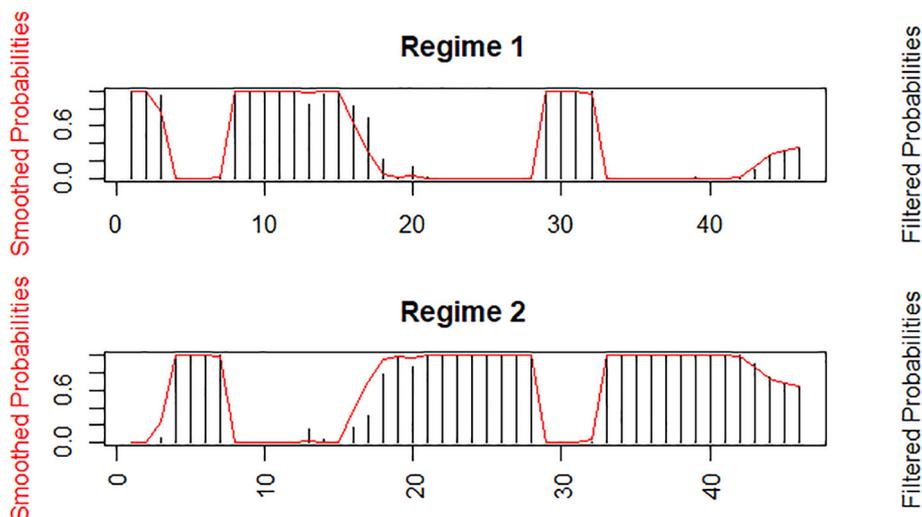


Fig. 4b. Graphical representation of Regime 1 and 2 with respect to Section A of Table 10.

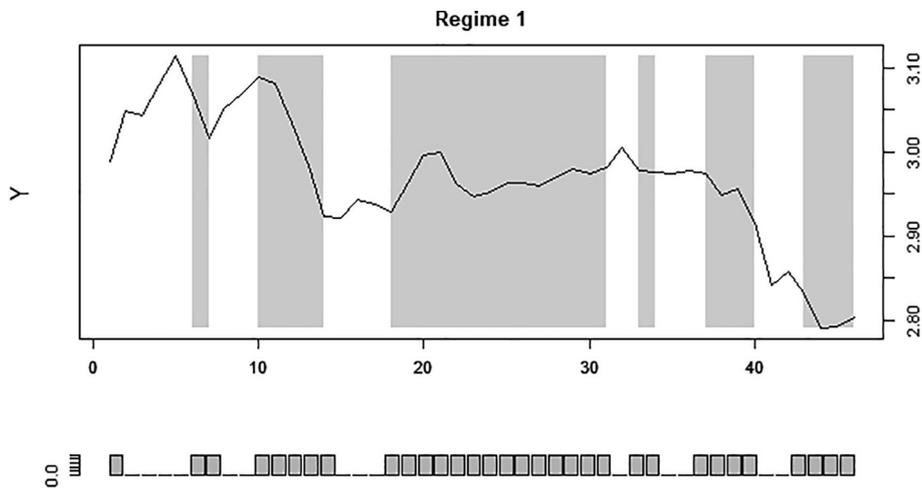


Fig. 5a. Graphical representation of Regime 1 with respect to Section B of Table 10.

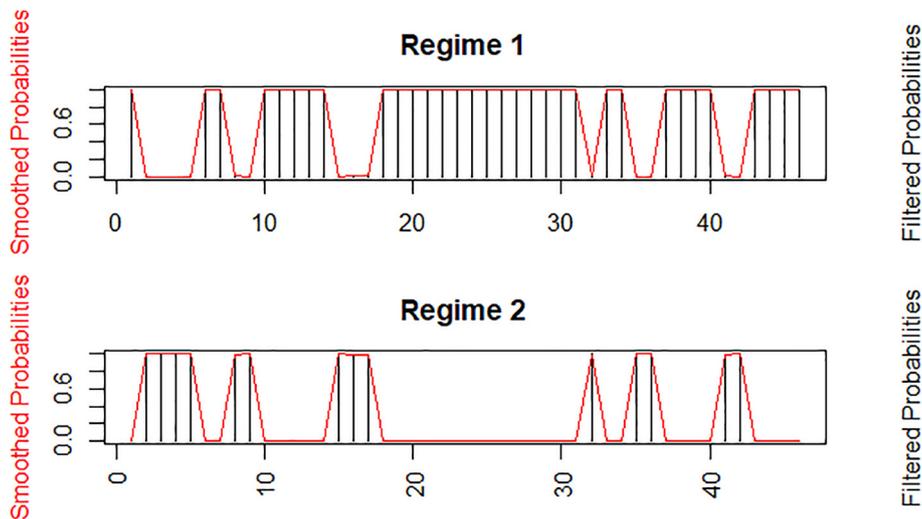


Fig. 5b. Graphical representation of Regime 1 and 2 with respect to Section B of Table 10.

tion probabilities, and here too we focus only on section B of Table 10 mainly because, the signs of how LR impacts on CO₂ in both regimes are opposite to each other. These conflicting impacts make section B an important case for policymaking. According to results from Table 11, there is an 81% chance that regime 1 will occur compared to 19% for regime 2. In addition, the results indicate the probability of transition from regime 1 to 2, as 43%. Consequently, transition probability from regime 2 to 1, is 57%.

Finally, graphical representations of diagnostic tests for the Markov Regime-Switching technique are presented in Figs. 6–8. We only presented the diagnostic test covering section B of Table 10 since it is not very different from that of section A. It is clear from Fig. 6 that in both regimes, the residuals form random plots around the line pass-

ing through point zero. This is consistent with the condition required for obtaining Best Linear and Unbiased Estimates (BLUE). If this condition is met, the residuals must have a normal distribution with mean

Table 11

Transition probabilities for section B of Table 10.

| | REGIME 1 (%) | REGIME 2 (%) |
|----------|--------------|--------------|
| REGIME 1 | 81 | 43 |
| REGIME 2 | 19 | 57 |

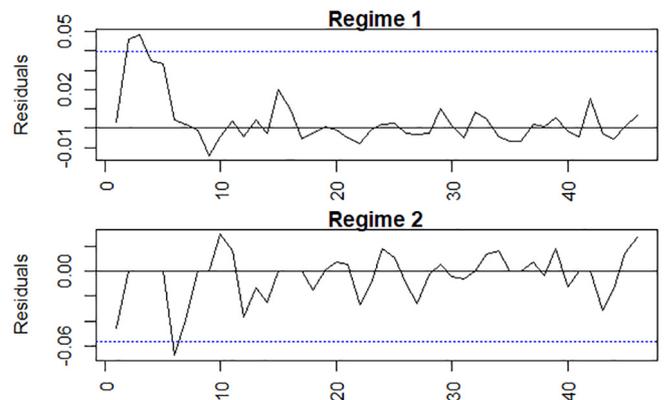


Fig. 6. Plot of residuals against fitted values section B of Table 10.

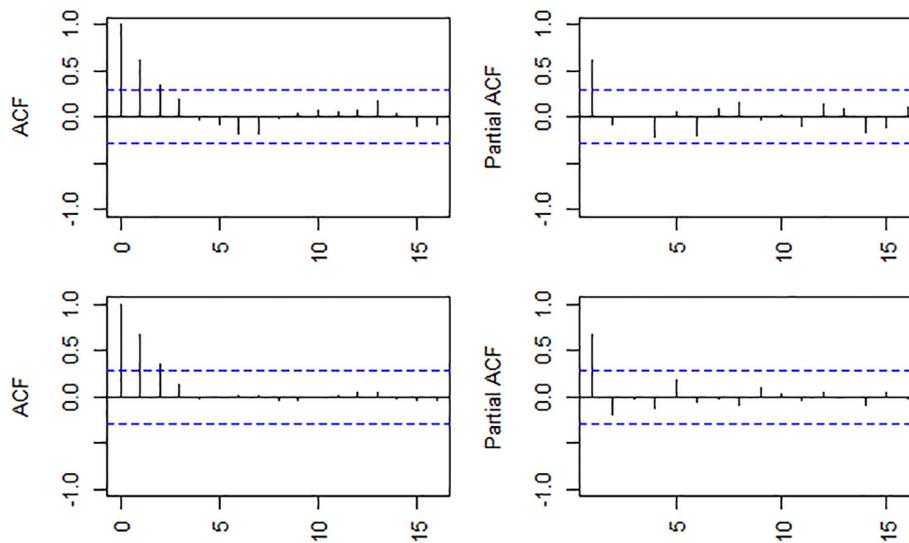


Fig. 7. ACF/PACF of Residual for Section B of Table 10: Regime 1.

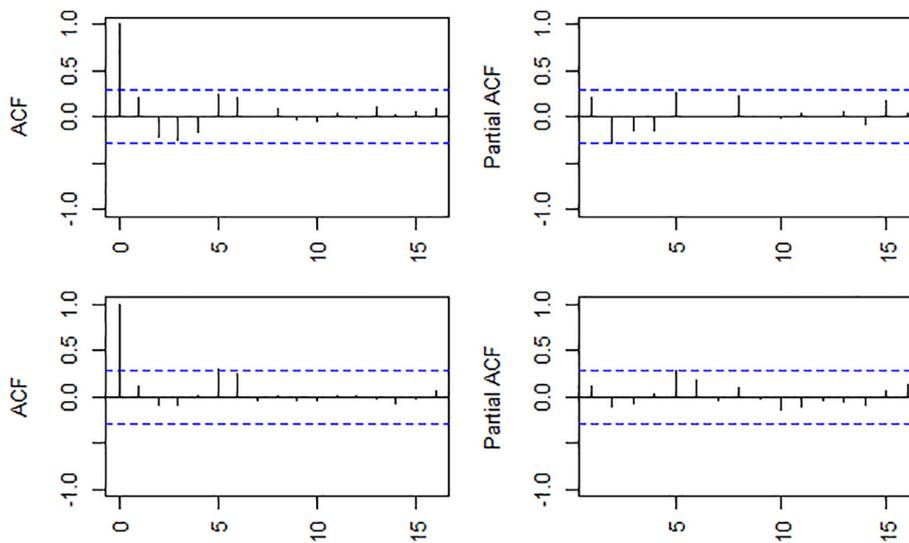


Fig. 8. ACF/PACF of Residual for Section B of Table 10: Regime 2.

equal to zero similar to what is shown in Fig. 6. Another condition for achieving blue is the absence of serial correlation among the residuals. This can be checked using the autocorrelation function (ACF) (Hondroyiannis & Papapetrou, 2006) and partial autocorrelation function (PACF) of the residuals. Figs. 7 and 8 exhibit ACF and PACF of regimes 1 and 2 respectively, and they indicate that, the plot of series from the residuals die off quickly after some few lags. Such a feature is associated with stationarity, and the absence of serial correlation. In this regard, the resultant coefficients from the analysis can be considered as accurate and efficient.

5. Discussion of results

Establishing the existence of cointegration among the variables implies that, the impact Lending rate exerts on CO₂ emissions has a theoretical basis. Being the most exogenous variable means that Lending rate cannot be targeted by the US Federal Reserve. What accounts for the level of Lending rate is the free flow of capital across the borders of the US economy. This in itself depends on many factors

including return on investments. Investors will move their funds into the US economy only if interest rates are attractive. The reverse is true when interest rates are low compared to other jurisdictions. Due to the liberalization of the financial sector, the flow of financial assets in and outside the US economy cannot be controlled. However, the free flow of funds subsequently affects the level of Lending interest rates (Illes, Lombardi, & Mizzen, 2019). Thus, the influx of excessive funds causes the Lending rate to fall. In the event that, the US experiences capital flight, the Lending rate will shoot up. Controlling Lending rate though, is possible when the Federal Reserve employs the appropriate Open market operations (OMO). In this direction, the Lending rate can be used to control pollution. But since GDP lies between Lending rate and CO₂ emissions in the chain of Granger causality, care should be taken so that growth is not adversely affected in an attempt to employ Lending rate to control pollution.

On its own, Lending rate reduces pollution based on its negative relationship with CO₂. Quantitatively, a 1% increase in Lending rate reduces CO₂ by 0.004 (19.512 * 0.02%) metric tons per capita. This result reflects the reality that, only individuals and firms in good financial standing have the capacity to borrow at high-interest rates. Such

entities undoubtedly have the capabilities and “economies” of scale (Dodman, 2009), to acquire high-technology, and environmentally friendly equipment and machinery for their operational activities. Therefore high lending interest rates would serve as a barrier on the activities of the less endowed entities and microenterprises (Glackin, 2002), who might be responsible for dissipating huge amounts of pollutants into the environment. When economic agents responsible for causing substantial amounts of pollution are unable to operate at full capacity due to financial difficulties based on high Lending rate, the resultant impact is a reduction in pollution.

Another reason why Lending rate seems to reduce pollution emanates from the possible scaling down of activities by all economic agents because they are unable to borrow at high-interest rates. In this scenario, it is assumed that all agents are efficient and employ environmentally friendly equipment and machinery in their operations. However, the amount of CO₂ emitted is reduced mainly because, lack of funds has caused a reduction in their activities.

On the contrary, when interaction variables FDLR, ENLR, and LYLR are included in the regression, the negative relationship between Lending rate and CO₂ emissions is not significant. With the inclusion of FDLR, ENLR, and LYLR, we seek to estimate the overall impact of LR under conditions of increasing financial development, energy consumption, and economic growth respectively. Only LYLR is found to have a significant impact on CO₂ emissions in normal regression. The positive impact exhibited by LYLR indicates that growth moderates a positive relationship between Lending rate and CO₂ emissions. This phenomenon seems to suggest that during increased economic activities, accompanied by increased production, emissions, and waste (Grossman, 1995), when all economic agents strive to meet their obligations, high Lending rate puts an extra burden on them. Neglecting good environmental practices, seems to be the only rational path economic agents would adopt, under the circumstances.

Other results worthy of discussions include the impacts of FD, EN, and Y, on pollution. In this regard, the results show that there exists a positive relationship between financial development and CO₂ emissions though not significant. This result is partly similar to the findings of Taghvaei et al. (2016) who found financial development in Iran as having a positive impact on carbon emission, but in this case, the impact was significant and in the short run. It also supports Boutabba (2014) whose work revealed that financial development in India impacts positively on carbon emissions thereby, enhancing environmental degradation. However, when compared with the work of Jalil and Feridun (2011), a clear contradiction is found. Their results show financial development as having a negative impact on carbon emissions and hence improves environmental quality in China.

Unlike financial development, energy consumption has a significantly positive association with CO₂ (Charfeddine & Kahia, 2019). This result is expected since the burning of fossil oil leads to the emission of carbon dioxide which is not suitable for the environment. In terms of causality, our results support the findings of Soytaş, Sari, and Ewing (2007) who report that energy use Granger causes carbon emissions in the US, but disagree with their assertion that income does not Granger cause same. The source of disagreement might be due to differences in methodology, as they employed Toda-Yamamoto (TY) in testing for long-run Granger causality. On the contrary also, is the findings with respect to Turkey, where a unidirectional causality originating from carbon emissions to energy consumption is reported (Soytaş & Sari, 2009).

As expected for most developed countries, growth is negatively related to CO₂ emissions, and this relationship is significant. This shows that as countries developed, manufacturing and energy utilization processes must be equipped with modern technology to reduce environmental pollution. Considering Granger causality, our findings are at par with the work of Zhang and Cheng (2009) when they report that, income leads both energy use and carbon emission in China. But as far as the long run relationship between income and carbon

emissions is concerned, our result is variant from that of (Soytaş & Sari, 2009). They found no long-run causal link between income and carbon emissions which is contrary to our findings.

The rest of the results show the control variables having varying impacts on pollution. Trade Volume and Urban Population show a positive and significant impact on pollution. Exhibiting a positive impact also is Population Density, but this relationship is not significant. Lastly, Labour Force and CO₂ emissions are associated negatively and significantly.

Most importantly, this paper is interested in ascertaining whether the coefficient of Lending rate remains constant under different regimes whether economic or otherwise. On its own and without the inclusion of interaction variables in the regression, the Lending rate continues to exhibit a negative impact on CO₂ emissions, whether under crisis or stable economic conditions. Despite exhibiting negative relationship in both regimes, it is only during periods of sound economic conditions, in this case, regime 2, that the relationship appears significant.

Firstly, we provide an analysis of the results from the Markov Regime-Switching technique of Section A, which was without the interaction variables. The composition of regime 1 which is characterized by a period of economic difficulties consist of periods 1969–71, 1976–84, 1997–2000, and 2011–2014. It would be realized that the period 1969–71 captures the recession of 1969–1970 which saw a slowdown of growth in the USA (Fabricant, 1972). The period 1976–84 covers the Mexico crash of 1976 (Ros & Rodriguez, 1987)), and 1981–1982 US economic recession (Estrella & Mishkin, 1996), which was blamed on restrictive monetary policy. The global economic crisis (or the global debt crisis) which is said to have originated from Thailand in 1997 (Stiglitz, 2000), quickly spread to other parts of South-East Asia, and by 1998, it had reached Russia. Also associated with this regime is the period 2011–2014 in which about 80% of global economies experienced lower average growth (United Nations, 2015).

As far as the results of the Markov regime-switching in section A are concerned, it seemed conclusive that Lending rate improves the environment, because it leads to a reduction in CO₂ emissions in both regimes. Consequently, the result that requires the attention of policy makers, is the reduction in CO₂ emissions by 0.013% that occurs only under sound economic conditions, for a 1% increase in Lending rate. A computation of this reduction using the average value of CO₂, amounts to 0.0025 metric tons per capita. Without using the regime-switching technique, we would have erroneously relied on 0.018% as the reduction to be realized from the impact of Lending rate.

Secondly, we analyze the regimes of the second Markov regime-switching technique, in which all the interaction variables were included in the regression. It is realized that most of the events in regime 1 of section B are similar to those found in regime 1 of section A. But there exist certain additional events which were not in regime 1 of section A. They include events which occurred in 1973–1974, 2001–2002, and 2005–2008. It is on record that the economic recession in Western Europe occurred in 1973–1974 (Jennissen, 2003), which presumably resulted from persistent inflation and strikes. Again in 1973 saw the oil embargo (Yang, Hwang, & Huang, 2002) placed on the US which led to stagflation and oil crisis. This regime also captures the event of 2001, when many developed countries experienced a decline in economic activities (Giertz & Giertz, 2004), a fate which the US suffered a year later in 2002. Finally, the period 2005–2008 captures most part of the global financial crisis (Cheung, Fung, & Tsai, 2010), and the riots in Greece (Kalyvas, 2010). Considering the events outlined above, inferences can be made to the effect that, in connection with section B, regime 1 is characterized to include economic recessions, financial uncertainty, international conflicts, and political upheavals. Regime 2, therefore, reflects the contrary, and hence characterized by economic and financial stability, stable political climate, and peaceful coexistence among the community of nations.

Results of the Regime-Switching technique accordingly implies that growth, energy consumption, and financial development, simultaneously moderate the relationship between Lending rate and CO₂ emissions during sound conditions. The results further indicate that, under conditions of economic downturns, financial turbulence, conflicts, and political disturbances, Lending rate leads to an increase in CO₂ emissions. Therefore the inclusion of the interaction variables suggests that under unfavorable conditions, increase in lender rate leads to a deterioration of the environment. It is expected that under such harsh conditions, unemployment, inflation, and prices of metals, minerals, and energy (Grossman, 1995) are likely to shoot up. Any additional cost arising from the increase in Lending rate may put economic agents under unbearable pressure.

To survive such harsh conditions, economic agents especially manufacturing firms will have to adopt cost-cutting measures. Firstly, they may abandon processes that are necessary for safeguarding the integrity of the environment. Secondly, they are likely to employ the use of certain equipment, and inputs in their operations that are convenient or less costly, but potentially harmful to the environment. For instance, even though emissions from incineration processes are larger than those that use natural gas in energy production (Damgaard, Riber, Fruergaard, Hulgaard, & Christensen, 2010), the latter is avoided. Under harsh conditions, it should be expected that firms would revert to incineration processes. On the part of citizens, their preference for low-cost industrial products, which might emit large quantities of carbon dioxide, would supersede more environmentally efficient but high-cost products. If this condition prevails, the results further indicate that the overall impact of a 1% rise in Lending rate, is an increase in CO₂ emissions by 1.08%, equivalent to 0.2107 metric tons per capita.

Furthermore, it should be noted that the inclusion of the interaction variables means that, the economy is growing, energy consumption is increasing, and credit to the private sector is on the ascendancy. Hence individuals have enough income to demand goods and services. Likewise, suppliers have access to credit, and the growing economy provides an incentive to engage in production. The only limitation to demand and supply is the high-interest rate at which banks lend to economic agents. If these economic agents must surmount this barrier, the analysis seems to indicate that, they will sacrifice the environment to achieve their objectives.

Conversely, in the midst of increasing growth, energy usage, and financial sector, and under stable economic, financial, political, and international relations, Lending rate reduces CO₂ emissions. The scenario here suggests some reasons for this result. Due to the additional cost imposed by a high Lending rate, we humbly share the following opinions;

- I. Not all firms would have the capacity to access credit at the high Lending rate, leading to a scaling down of their operations. Hence CO₂ levels will fall compared to if firms were to undertake full-scale operations.
- II. Only firms in good financial standing have the capacity to borrow at high-interest rates. Such firms we believe are well equipped with the machinery to reduce CO₂ emissions arising from their operations.
- III. If firms and citizens were to take advantage of the growing economy and credit to the private sector, it should be possible for them to acquire high-technology (Grossman, 1995) machinery that are environmentally friendly.

Consequently, with the inclusion of the interaction variables and under favorable conditions, the results indicate the overall impact of a 1% increase in Lending rate, to be a reduction in CO₂ emissions by 0.70%. This is equivalent to 0.1366 metric tons per capita.

From the above analysis and discussions the points below may suffice as our main findings:

- a) The lending rate is found to be the most exogenous variable, and Granger causes all the other main variables in the energy economics nexus. This finding is significant in that, it seems to suggest the problem of pollution to have originated from rising Lending rate. This implies that the lending interest rate can be used to control pollution. However since Lending rate also causes growth in the long run, its use in controlling pollution might have implications for growth in the US.
- b) On its own, the Lending rate is negatively related to CO₂ emissions, and this relationship remains same under different regimes. However, the relationship is significant under sound and stable economic regimes, and not significant during periods of economic recession.
- c) When increasing economic growth, energy consumption, and financial sector prevail, the Lending rate is negatively related to CO₂ emissions, though not significantly. Under unstable economic, financial, political and international relations, the relationship is significantly positive, otherwise, it is negative and significant.

6. Conclusion and policy implications

The energy economics literature has given substantial attention to how growth, financial development, and energy consumption affect pollution. Despite the existence of many theories and empirical work in this body of knowledge, contradictions in findings are the reason for continuous interest in further work in the subject. To the best of our knowledge, the impact of lending interest rate on Carbon emissions is a gap that exists in literature. Hence, this paper's main objective is to firstly, determine whether long-run causal relationship exists between Lending rate and pollution, secondly, to estimate the impact of Lending rate on pollution, and lastly, to investigate whether the relationship between them is linear.

A perusal of literature clearly identifies growth, energy consumption, financial development, and carbon emissions as the main variables in the energy economics nexus. These variables together with Lending rate were the subject matter for which the existence of cointegration was to be determined in this paper. We analyzed annual time series data of the USA covering 1968–2014 using standard econometric techniques, dynamic OLS, and Markov Regime-Switching method to arrive at the following findings:

1. Lending rate Granger causes carbon dioxide emissions in the USA in the long run
2. On its own, Lending rate has a negative impact on carbon emissions and hence improves environmental quality. This impact remains same irrespective of whether economic conditions are sound or in crisis.
3. Financial development, energy consumption, and growth appear to simultaneously moderate in the Lending rate-Carbon emissions relationship, only when socio-economic, political, and international relations are sound. Lending rate and Carbon emissions are positively and significantly associated during periods of crisis. However, the relationship becomes negative during periods of stability and soundness. Hence the relationship between Lending rate and Carbon emissions can be said to be non-linear.

From the aforementioned findings, Lending rate appears like a "double-edged knife" that cuts at both sides. It can lead to the improvement of the environment and also cause its deterioration. This situation therefore, requires careful attention to mitigate its impact for the achievement of a sustainable quality environment. Our findings have far-reaching implications for policymaking.

Being the most exogenous of all the variables employed, Lending rate can be used to control pollution. It also implies that its value is determined by external forces. With the kind of liberalization the

financial sector in the US enjoys, and the accompanying movement of funds across its borders, it would be difficult to target Lending rate. But it is not impossible for the US Federal Reserve, to use appropriate open market operations for the purposes of achieving the desired rate that enhances environmental quality. The Federal Reserve System must therefore, intervene when the Lending rate is rising especially, during crisis periods.

Agencies responsible for supervising waste treatment activities of economic agents, and those responsible for monitoring pollution levels in the US, must now consider Lending rate movements, especially during crisis periods, as an important factor that must be closely watched. The Environmental Protection Agency (EPA) must intensify their oversight activities aimed at ensuring responsible environmental practices by firms. If the findings are anything to go by, existing laws and regulations are not enough to deter firms from being careless towards the environment when they are faced with high Lending interest rates. To ensure that toxic waste is not dumped on to the environment, close supervision and monitoring of firms are highly recommended during crisis and periods of high Lending rate.

Banks also have a crucial role to play in securing a healthy environment. Taking a cue from the findings of this study, the first course of action expected from their outfit will be to restrain themselves from increasing Lending rate during times of crisis and instability. But most importantly, they must ensure all firms that intend accessing funding from them, take environmental quality concerns seriously. In this respect, all banks should be encouraged to embrace the Equator principles for responsible financing. Recently, it is common practice for stakeholders to request firms to show their commitment to sustainable development (Isaksson & Steimle, 2009), as part of efforts to encourage sustainability practices. In this regard, it would not be out of place for banks to request firms to provide sustainability reports, as a requirement in applying for loan facilities.

Finally, the US government has a pivotal role to play if enhancing environmental quality is to be achieved. Through the use of appropriate fiscal policies, the government can prevent the occurrence of economic crisis and downturns. There is also the need for building strong structures with capabilities of cushioning the US economy against contagion, and other external destabilizing factors. Furthermore, government should also use its privileged position in the United Nations (UN) and other international organizations, its global recognition, and all its resources to secure peace and stability throughout the globe. If these are achieved, conditions for which Lending rate impacts positively on pollution would be eliminated.

We suggest areas for further research to include, the use of panel data, short frequency data, and to investigate how profit rate affect pollution in an Islamic finance setting.

CRedit authorship contribution statement

Mohammed Yaw Broni: Conceptualization, Data curation, Formal analysis, Methodology, Software, Validation, Writing- original draft, Writing- review & editing. **Mosharrof Hosen:** Conceptualization, Data curation, Formal analysis, Methodology, Software, Validation, Writing- original draft, Writing- review & editing. **Hardi Nyagsi Mohammed:** Conceptualization, Writing- original draft, Writing- review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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