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TRADE OPENNESS AND CO2 EMISSION: EVIDENCE FROM NIGERIA

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ABSTRACT

This study embarked on an empirical investigation of the impact of trade openness on CO2 emission in Nigeria. The findings here indicate a nuanced relationship between trade openness, GDP, population, and CO2 emissions in Nigeria. We specifically observe that, trade openness which is the explanatory variable of utmost interest has a marginal positive impact on CO2 and NO2 emissions but reduces CH4 emissions. The results further reveal the unique perspective on sectoral dynamics in CO2 emissions. Fuel-related emissions are driven by rising income levels (YPC) and population growth (POPR), showing that economic and demographic expansion increase energy demand. On the other hand, trade flows (TRDF) have a smaller positive impact on fuel emissions, indicating limited influence. In manufacturing, emissions are strongly tied to industrial output (YMAN), with nearly proportional effects. These results fail to conform to traditional narratives and emphasize the complexity of emissions drivers in a diversifying economy. Similarly, the sectoral analysis highlights the role of economic activities in shaping emissions patterns and the need for targeted mitigation strategies.

KEYWORDS: Trade Openness; CO2 Emission, GMM

INTRODUCTION

The interrelation between trade openness and CO2 emission has generated keen interest from academic and policy analysis. It has been argued that trade policies can be used as a virile tool to influence vulnerability/mitigation of the effects of CO2 emissions. Interestingly, this debate has traditionally been designed within the framework of industry responses to trade policy. While these responses hinge on the behavior of individual polluters within each industry; very little is known about how trade policy affects the pollution emitted by individual plants especially in developing countries. This has been attributed to the lack of disaggregate and micro-level plant/industry data on emissions.

It has been argued that this popular notion that trade is one of the key underlying drivers of greenhouse gases emissions that exacerbate climate change through its effects on the location and scale of production, consumption decisions, emissions from the international transporting of goods and services is not a definitive truth. This is because trade also occupies a central part of the solution for enhancing mitigation of vulnerability and adaption to climate change generated from CO2 emissions through the transfer of technologies that may lead to lower emissions in production. However, most recent estimates show that around a quarter of all global emissions are linked to international trade flows (Brenton, Paul, and Vicky Chemutai, 2021, World Bank, 2022).

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Available data show that global trade flows has continued to expand and so has carbon emission and the attendant negative outcome on climate change vulnerability. This has led to question regarding the interlink between trade and climate change. Early studies such as Copeland & Taylor (2001), Grossman and Krueger (1991), have describe three channels through which trade policies may affect the environment and lead to worsening climate change. They include the scale effects, the technical effects and composition effects. The composition effect and technical effects are directly related to the structural peculiarities of sub-Saharan African countries production and trade. In the case of a low-carbon transition, as the structure of economies changes, the total volume of emissions may decrease, less emission-intensive sectors expand and more emission-intensive contract.

The first channel is the scale-effect: if production and output scale up as a result of increased trade, this also leads to upscaling related pollution. The second channel is the technique effect which refers to the advancing techniques of production that are likely to accompany liberalized trade policies. These may be due to income-induced demand for greater access to environmentally beneficial production technologies and for greater environmental regulations (WTO, 2020). Finally, the composition effect refers to the changing composition of an economy that may occur following an episode of increased trade liberalization policies as countries increasingly specialize in activities in which they enjoy a comparative advantage.

These channels are often driven by different factors, first is environmental policy and second and most obviously trade policy. The composition effects are most relevant to the trade-climate change nexus and has served as the mechanism through which the theory of Pollution Haven Hypothesis (hereinafter PHH) is derived. However, how the composition effect of trade affects climate change depends on a country specific source of comparative advantage of production intensity and more specifically on whether the country's comparative advantage is domiciled in a pollution intensive production. In this sense, trade therefore can affect the pollution emitted per unit of output or per unit of value added within industries and thus the pollution intensity of production: the same amount of a given product is produced with more or less pollution (Cole, 2004).

On the global stage, the volume of trade continues to increase, however the contribution of less developed countries especially those in sub-Saharan African still remains negligible. Interestingly even while contributing insignificantly to carbon dioxide (hereinafter, CO2) emissions it has been well documented that developing countries like Nigeria are the most vulnerable to climate change. This is primarily because they lack the necessary resources, infrastructure and technology to mitigate the effect of climate change on the environment (Ogbuabor **and** Egwuchukwu, 2017). Again, given the transfer of emissions among countries along global value chains, it is important to understand the country-specific territorial emissions embedded in exports and those transferred from imports (Brenton, et. al. 2023).

The preceding arguments give the impetuous to examine the trade-climate change nexus within the context of a small open economy like Nigeria. Only a handful of papers have examined the interlink between trade policies on climate change vulnerability for Nigeria (Ogbuabor **and** Egwuchukwu, 2017; Nwosu et. al. 2023). The results from these studies have generated mixed findings. A clear indication of the extent to which the trade policy may be exacerbating CO2 emissions and further worsening climate change vulnerability is yet to be provided. Most of these literature concentrates on the impact of climate change on economic activities especially in agriculture in Nigeria.

We make contribution to the nascent literature that relates to the trade and CO2 emissions nexus using detailed industry/sector level data on trade flows, this paper examines the evidence for the trade-climate change nexus. More specifically, the paper assesses the extent to which trade liberalization influence pollution emissions and ascertains whether these trade patterns could be determined by divergent environmental regulations between the North and the South.

The paper will proceed from here as follows. Section 2 presents some very general stylized facts about the linkages between trade and climate change, thereby putting the rest of the literature into perspective. Section 3 deals with measuring and modeling trade policy along the econometric of Environmental Kuznets Curve (EKC) analysis.

Section 4 provides empirical estimates, trade policy and climate change while Section 6 concludes.

Review of Previous Studies

Early works in the trade and climate change literature such as Markusen (2013); Copeland (2010); Hoel (1996), focused on using partial equilibrium or two-country models to study how unilaterally-applied trade tariff can mitigate transboundary environmental damages. These studies show that trade policies can impact on climate change through channels such as greenhouse gas emissions, environmental regulation and climate change adaptation and mitigation strategies. Before commencing the review of previous studies, it is pertinent to present a brief analysis of some data on trade and climate change.

According to WTO (2023) international goods trade increased relative to global GDP by around 62% between 1990 and 2022, and reached an absolute all time high at 5.6 trillion USD in the third quarter of 2021 (UNCTAD (2021). The number of environmental impacts embodied in trade has also been on the increase. Copeland et al. (2021) use data for carbon dioxide (CO2) and Nitrogen Oxides (NOx) from 1990 until 2009 showing that the shares of emissions embodied in international trade for both types of emissions rose almost continuously over time, reaching a peak in 2008.

Globally, evidence from recent estimates, show that carbon dioxide (CO2) emissions associated with the production and distribution of traded goods and services amounts to 8 billion tons which constitute a quarter of total global emissions 32 billion tons (Banque de France 2020). Additionally, high-income advance countries collectively have higher consumption-based emissions (the United States imports 15 percent of the 8 billion tons for consumption) than territory-based emissions. This indicates that the United Stated States despite being an advanced economy is still a net importer of emissions and thus benefit from carbon-intensive production abroad domiciled in countries with low environmental laws (Arto and Dietzenbacher 2014). These effects are growing over time, and the net transfer of emissions (production minus consumption) via international trade from high-income to low- and middle-income countries has continued to increase (Peters et al. 2011).

This is also in line with data from Peters et al. (2011) for CO2-emissions. Peters et al. (2011) has equally emphasized that non–energy-intensive manufacturing had a key role in the emission transfers since it accounted for a growing share of 30% as at 2008 of global exported CO2-emissions. Copeland et al. (2021) report that in 2008 around 35% of global CO2 emissions and 32% of NOx emissions were embodied in traded goods and services. Generally, in their data, the share varies between a fourth to a third of global CO2 / NOX emissions. These effects are growing over time, and the net transfer of emissions (production minus consumption) via international trade from high-income to low- and middle-income countries has continued to increase.

More recent research by Kortum and Weisbach (2020) and Weisbach et al. (2023) characterizes unilaterally-optimal carbon policy in a two-country model put forward by Dornbusch et al (1977), emphasizing the effectiveness of combining supply and demand-side carbon taxes. Another strand of the literature examines multilateral policies, and the linkages between trade policy and climate policy. Notably among such studies is Cole and Elliott (2017) and (Nordhaus, 2015) which provide a detailed examination of trade and climate change nexus within the framework of the Pollution Haven Hypothesis (PHH). They provide evidence indicating that trade liberalization leads to the relocation of pollution-intensive industries from advanced countries to countries with weaker environmental regulations, however, the noted that the overall impact is moderated by factors like industry composition and technological transfer and diffusion. They conclude that trade's environmental impact is complex and context-dependent, calling for nuanced policy responses. The indeterminate conclusion reported from the empirical evidence in their results may be attributed to their reliance on aggregate data and the attending consequence of obscuring industry-specific dynamic.

Interestingly, other studies have also utilized quantitative approach to investigate the environmental and energy related policies in open economies while accounting for industry level heterogeneity (Elliott et al. 2013; Taheripour et al. 2019).

For instance, Farrokhi and LashKaripour (2021) analyzed the efficacy of carbon border adjustment policies by deriving climate externalities within the framework of a multi-country, multi-industry general equilibrium model of trade showed that border taxes, when used as non-contingent, indirect mechanisms for carbon taxation, have limited potential to mitigate global emissions even under optimal design. More specifically, they show that the optimal unilateral energy emission policy can be implemented with a combination of a carbon tariff and industry-specific production subsidies, import taxes, and export subsidies. They concluded that compared to the globally optimal policy mix, carbon taxes are set too low as they only internalize the part of the climate costs that is incurred by the specific country. Compared to a setting without a carbon externality, border taxes contain not only a terms of trade driven component, but a second carbon border tax component that aims at lowering carbon emissions abroad.

On the contrary, Nordhaus's (2015) had previously argued that the use of border taxes as contingent penalties is highly effective in deterring free-riding. Other studies such as Bohringer et al. (2021); Larch and Wanner (2017); Shapiro (2021); Shapiro & Walker (2018) have also put forward their argument with empirical backings and varying specifications of the trade and global economy. Shapiro & Walker (2018) have different relative strengths in considering heterogenous versus homogeneous firms, incorporating firm level. Consequently, the results have been and has revealed no clear-cut framework through which the full potential of trade policy for reducing carbon emissions.

Theoretical Issues in Trade Policy and CO2 Emissions

Trade policy are instruments used to regulate the flow and volume of trade in a country. The direction of trade can be viewed through the trade policy stipulated. For instance, countries with intention to liberalize trade will reduce tariff so as to encourage imports and exports. Tariff are the most quantifiable and important trade policy instrument easily employed to regulate trade. Guimbard et al. 2012 have argued that non-tariff barriers (hereafter, NTBs) have also featured prominently.

Trade flows in sector such as manufacturing, energy and fuel consumption has also been increasing for Nigeria as reported by WDI. While the changes in tariff policies in Nigeria are small relative to the changes in trade policy that occurred during other recent episodes of trade liberalization, Caliendo and Parro (2015) has shown that these policy changes could have large effect on trade. Moreover, changes in tariff vary across industries.

It has been shown that the incidence of CO2 emissions could originate from two major sources. First, an industry (say industry A) which engages in production activities that burns fossil fuels to produce output. Second, another industry (say industry B) which purchases intermediate goods as inputs that themselves require CO2 emissions to produce. The first channel is described by Shapiro (2020) as the "direct" effect of CO2 emissions and the second as "indirect" effect.

Recently, the development of global value chains and the associated international input-output linkages have also found their way into other types of quantitative theory models of trade and CO2 emissions and hence climate change, which had previously focused on final goods trade (Larch & Wanner (2017), (2019); Shapiro & Walker (2018)) or simplified versions of intermediate goods trade (Egger & Nigai (2015); Shapiro (2021) incorporates multi-regional, multi-industry IO-linkages following Caliendo & Parro (2015) into his quantitative model which he uses to assess the environmental bias of current trade policies.

In a similar fashion, Caron & Fally (2022) combine a trade model structure with a more elaborate modelling of the energy sectors, distinguishing primary and secondary fossil fuels while explicitly incorporating natural resources, additionally adding non-homothetic preferences. They investigate the emission effects of changing international consumption patterns and find that the shift towards less energy-intensive consumption at high income levels becomes less pronounced once emissions along the whole value chain are taken into account. Mahlkow & Wanner (2023) also use a gravity-type global value chain general equilibrium Ricardian trade model to consider the climate change implications of global trade imbalances. They show how the model allows different kinds of carbon accounting, namely attributing emissions either to the country where they occur (production footprints), the country where the products associated with the emissions end up being consumed (consumption footprints), or the country where the fossil fuels originated from (supply or extraction footprints).

They find that current global trade imbalances significantly contribute to global emissions.

THE MODEL

Trade and CO2 Emissions

The empirical model adopted in the study follows an eclectic approach and borrows from previous studies in the empirical stipulation such as Shapiro (2020); Besedes and Moreno-Cruz (2016) and Cherniwchan (2017). We begin by stating that greenhouse gases (CO2, CH4 and NO2) are biggest use of Climate Change Vulnerability (CCV). In this sense, we insinuate that increase in GHG emissions equates increase in CCV. It is pertinent to state that just like Cherniwchan (2017), we carry out the empirical specification first by using an aggregated data set for trade and CO2 emission, thereby deriving the overall impact of trade on CCV. We proceed further by examining the separate impact of each CO2 emitting industry. This is to help identify the linkage between industry level emission and CCV.

To examine the impact of trade on CO2 emission, this paper first assumes that there is a linear relationship between international trade and CO2 emission performance. It establishes a simplified baseline model as follows;

$$V_t = \rho TRD_t + \mu_t \quad (1)$$

Equation 1 is used to hypothesize the relationship between trade and CCV using CO2 emissions as proxy and assumes that increase in CO2 emission equates increased CCV. The variable (V_t) is a vector of GHG emissions including CO2, CH4 and NO2. The main explanatory variable, TRD_t, represents the volume of trade as a percentage of GDP. Finally, μ_t is an error term that captures idiosyncratic changes in vulnerability.

Climate Change Vulnerability and Gross Domestic product (GDP) Per Capita

The study estimates a separate regression for some political economy variables F_t as specified in equation 2 below and then examine which of these variables increases CO2 emissions. The estimation is implemented using ordinary least squares estimation regression and the generalized method of moments to account for the possible presence of endogeneity that may be present in the variables.

$$V_t = \rho TRD_t + \pi F_t + \mu_t \quad (2)$$

In equation 2, F_t is a vector that includes potential political economy variable that act as control variables in the model. This typically includes variables such as GDP per capita, manufacturing output, manufacturing trade etc. that are likely to have impact on CO2 emission.

Existing literature has demonstrated that the relationship between trade and CO2 emissions may be affected by different levels of income, and the heterogeneous impact of income can be tested by interaction terms or by squaring the income variable (Managi et al. 2009; Du and Li 2019).

Based on previous studies, this paper further extends the impact of income levels into the research on CO2 emission performance, and the effect of income is analyzed through the similar empirical strategy. Specifically, this paper assumes that the impact of trade openness on CO2 emission performance is a simple function of income level.

Revisiting the Scale and Composition Effects

Increase in the volume of economic activities as well as the industrial composition and intensity of such activities are likely to have significant impact on CO2 emission and thus on CCV. Hence, all things being equal an economy with a higher GDP level and higher share of industry and manufacturing proportion of its output will have increased CO2 emission. This proposition is the core of the trade-environment nexus put forward by Grossman and Krueger (1991). In evaluating the plausibility of the existence of these effects for Nigeria, equation 3 is specified as below;

$$V_t = \varphi_1 Y_t + \varphi_2 Y_t^2 + \varphi_3 MY_t + \mu_t \quad (3)$$

Equation 3 describes the economic determinants of CO2 emission. The parameters φ_2 and φ_3 are the measure of the scale and composition effects respectively. It is assumed all things being equal an economy with a larger production scale emits more GHG, hence $\varphi_2 > 0$. The composition effect is captured by the parameter φ_3 which reflects pollution performance of an economy's industrial composition. Given the same production, industrial composition contains greater percentage of GHG emitting sectors. Thus, it is expected that φ_3 will be positive $\varphi_3 > 0$.

Data and Empirical Strategy

Data

For the empirical purpose, this study employs annual times series data for the selected variables for Nigeria. The main source of the data i.s the World Bank's WDI database and IMF National Climate Change Contribution database. The data covers the period 1990 to 2022. A summary of the description of the variables and their sources are presented in table 1 below.

Table 1: Description of Variables

S/N	VarCode	Description	Source
1	YTrd	Total Trade as % of GDP (Export + Import divided by GDP)	WDI
2	TFue	Total Trade in Fuel and Energy Products as % of GDP	WDI
3	YTMa	Total Manufacturing Trade as a % of GDP	WDI
4	YGPc	GDP per capita (constant 2015 US$)	WDI
5	YGDP	GDP at Constant Basic Prices	WDI
6	YMPc	Manufacturing Output Per Capita	WDI
7	YMan	Manufacturing Output	WDI
8	CO2	Total CO2 Emission	WDI
9	CH4	Total Methane (CH4) Emission	WDI
10	NO2	Total Nitrogen (NO2) Emission	WDI

Sectoral Contribution of GHG emissions in Nigeria

In this subsection, we present a brief compilation of GHG emission for some selected sectors of the Nigerian economy from 1990 to 2022 using decadal breaks. The sectors include, agriculture, building, energy, fuel, manufacturing, and transport. This section describes salient facts from these data because they provide novel evidence on how different sectors have contributed to carbon emissions over the years and which of the variable should enter the econometric model. This is shown in table 2 below.

Table 2 above shows that emissions due to production of energy and fuel accounted for the first and second highest CO2 and other GHG respectively. Surprising emissions from manufacturing production was the least. However, this can be explained by the fact that the Nigerian manufacturing sector still accounts for small proportion of the GDP. Production of agricultural products also featured prominent as a major source of emissions. For a developing economy like Nigeria where agriculture and other mining activities are the major trading commodities the evidence in the table is not surprising. It can be seen that energy and building emitted more of CH4 while the other remaining 4 sector emitted more of CO2. On the overall in can be seen that CO2 emission along with other GHG have maintained a steady increase over the years from 1990.

Table 2: CO2 emission from selected sectors

Source	Period	CO2	CH4	NO2	GHG
Agriculture	1990-2000	0.079433	29.92924	10.90633	40.91500
	2001-2010	0.221210	36.90975	14.11443	51.24539
	2011-2022	0.571266	51.89281	19.56532	72.02939
Building	1990-2000	4.398921	20.25314	2.554368	27.20643
	2001-2010	4.909852	26.28984	3.297112	34.49681
	2011-2022	4.875297	34.73084	4.336667	43.94280
Energy	1990-2000	86.99571	214.0824	2.984512	304.0626
	2001-2010	90.36156	198.2213	3.910225	292.4931
	2011-2022	102.6577	162.3222	5.244575	270.2245
Fuel	1990-2000	36.22432	20.44876	2.773133	59.44621
	2001-2010	51.85852	26.69282	3.689936	82.24128
	2011-2022	86.24825	35.39994	5.046399	126.6946
Manufacturing	1990-2000	3.457581	0.043788	0.055295	3.556665
	2001-2010	4.363642	0.135459	0.169193	4.668295
	2011-2022	7.111078	0.177588	0.221371	7.510037
Transport	1990-2000	17.11821	0.138209	0.154943	17.41136
	2001-2010	26.58218	0.244575	0.214449	27.04120
	2011-2022	48.90011	0.455204	0.475434	49.83075

Note: Data is obtained IMF-NCCC and decade average is computed by the author. The GHG emission data are measured in gigatons.

EMPIRICAL STRATEGY

Generalized Method of Moments

The GMM estimator for time series proposed by Hall (2005) has served as a robust alternative to the OLS method. The method is based on the same transformation but exploits more orthogonality conditions using a (possibly) larger set of instruments. Consistency for this estimator is established for large samples, while the number of overidentifying restrictions increases with t, This is because the lagged independent variable is used as an instrument (in levels).

For instance, consider a single equation linear GMM model below;

$$y_t = z_t'\delta_0 + \varepsilon_t, \qquad t = 1, \dots, n \qquad (4)$$

$E[z_{tk}\varepsilon_t] \neq 0$ for some k

Where z_t is an $L \times 1$ vector of explanatory variables, δ_0 is a vector of unknown coefficients and ε_t is a random error term. The model in equation 4 allows for the possibility that some of the elements in z_t may be correlated with the error term ε_t, as shown in the second part of equation 4. If $E[z_{tk}\varepsilon_t] \neq 0$ is true then z_{tk} is an endogenous variable.

This implies that the least squares estimator of δ_0 will be biased and inconsistent.

To resolve this, the GMM estimator assumes that there exist a $L \times 1$ vector of *instrumental variables* x_t which may contain some or all of the elements of z_t. Let w_t represent the vector of unique and non-constant elements of $\{y_t, z_t, x_t\}$. It is assumed that $\{w_t\}$ is a stationary and ergodic stochastic process. The instrumental variables $\{x_t\}$ satisfy the set of K orthogonality conditions.

$$E[g_t(w_t, \delta_0)] = E[(x_t, \varepsilon_t)] = E[x_t(y_t - z_t'\delta_0)] = 0 \quad (5)$$

Test for Non-Stationarity and Stationarity

The test for stationarity or non-stationarity is associated with the unit root properties of the times series. For instance, consider the stylized trend-cycle decomposition of a time series y_t:

$$y_t = D_t + \varepsilon_t \quad (6)$$

$$D_t = k + \theta t \qquad \varepsilon_t = \phi\varepsilon_{t-1} + \omega_t$$

Where D_t is a deterministic linear trend and ε_t is an $AR(1)$ process. If $|\phi| < 1$ then y_t is $I(0)$ about the deterministic trend D_t. If $\phi = 1$, then ε_t is a stochastic trend and y_t is $I(1)$ with drift. The $AR(1)$ model above is based on testing the null hypothesis that $\phi = 1$ (difference stationary) against the alternate hypothesis that $\phi < 1$ (trend stationary).

EMPIRICAL RESULTS.

Time Series Properties of Unit Root

We begin by interrogating the variables used for the analysis in such a way that allows us to better understand the time series properties of the variables. This will inform the specific variables to be included and the nature of the structural specification to be used. The paper utilizes the augmented Dickey-Fuller (ADF) and the Phillip-Perron (PP) test statistic to investigate the unit root properties of the time series. The result is presented in table 3 above.

The test is carried out under the trend and intercept specification. The lag length for the ADF is selected based on the AIC and SIC criterion while the bandwidth for the PP is based on the Newey-West method using Bartlett kernel.

The result from both the ADF and the PP test statistic are fairly similar. Both methods show that the variables are all stationary at first difference. Specifically, this indicates that at level, the time series possess a unit root and hence is not stationary. However, stationarity is induced by taking the first difference transformation of the time series.

Table 3: ADF and PP Unit Root Test Result

	ADF		PP		I(0)/I(1)
	Level	**1st Diff**	**Level**	**1st Diff.**	
Log_Top	-3.3910 (0.0704)	-5.4265* (0.0006)	-3.3214 (0.0809)	-18.3883** (0.0000)	I(1)
Log_gdpy	-1.6827 (0.7348)	-3.8980 (0.0470)	-1.7771 (0.6922)	-3.8543 (0.0422)	I(1)
Log_CO2	-1.8903 (0.6361)	-5.3928** (0.0007)	-2.0552 (0.5500)	-5.4053** (0.0006)	I(1)
Log_CH4	-1.6165 (0.7638)	-4.7122** (0.0036)	-1.8733 (0.6448)	-4.6726** (0.0039)	I(1)
Log_NO2	-2.6137 (0.2771)	-6.3931** (0.0000)	-2.6442 (0.2648)	-6.8700** (0.0000)	I(1)
Log_Pop	-2.2271 (0.4594)	-7.4647** (0.0000)	-2.1765 (0.4858)	-7.4647** (0.0000)	I(1)
Log_Fuecon	-2.8069 (0.2052)	-5.8020* (0.0002)	-2.7481 (0.2255)	-6.2229** (0.0001)	I(1)
Log_Renel	-1.9754 (0.5898)	-3.7485* (0.0342)	-2.9708 (0.1555)	-6.5036** (0.0000)	I(1)
Log_Urban	-2.2839 (0.4298)	-4.1504* (0.0333)	-1.6543 (0.7479)	-4.2111* (0.0246)	I(1)

Note: ** and * indicate significance at 1% and 5% respectively. Values in () are p-values of the test statistic.

Baseline Specification of the OLS and GMM Estimators

Table 4 reports the results of estimating the baseline specification using the OLS and the GMM estimator. The estimation specification captures the three main GHG (i.e., CO2, CH4 and NO2) as dependent variables. Panels 1 and 2 report the OLS and GMM results respectively. The two estimators provide fairly similar results, but the GMM estimates are slightly less significant than their OLS counterparts. In the GMM estimation the difference of the variables is used as the instruments and we find no evidence of a possible downward bias of the GMM estimator based on the regressor endogeneity test. In addition, the GMM estimators are also robust and estimates are more tightly than the OLS estimator. In what follows we therefore focus on the GMM estimator.

Table 4: Baseline Specification of the OLS and GMM Estimators

	Panel 1: OLS			Panel 2: GMM		
	CO2	**CH4**	**NO2**	**CO2**	**CH4**	**NO2**
C	7.1763**	18.2905**	-8.0012**	4.3866**	21.1884**	-2.7632
	(0.0001)	(0.0000)	(0.0000)	(0.0007)	(0.0000)	0.6567
LOG_TOP	0.0695*	0.0126	0.0166	0.1486	-0.0284	0.0492
	(0.0260)	(0.6701)	(0.3711)	(0.1160)	(0.5964)	(0.3331)
LOG_GDPY	-0.4137**	-0.0661	-0.1238	-0.8062*	-0.3233	-0.3233
	(0.0039)	(0.6142)	(0.1372)	(0.0112)	(0.0887)	(0.0813)
LOG(POP)	0.1798	-0.2142	1.1261**	1.4353**	-0.0026	1.1443
	(0.3291)	(0.2430)	(0.0000)	(0.0007)	(0.9891)	(0.0000)
LOG(URBR)	-0.2384*	-0.3903**	0.0310	-0.0317	-0.1507	0.1527
	(0.0263)	(0.0006)	(0.6246)	(0.9309)	(0.4520)	(0.5533)
LOG(FUECON)	0.6205**	0.3178**	0.1204	0.8624*	0.4485*	0.2544
	(0.0000)	(0.0054)	(0.0761)	(0.0478)	(0.0498)	(0.0919)
LOG(RENEL)	-0.2097*	-0.3173**	-0.0174	-0.4981	-0.5256*	-0.3228
	(0.0331)	(0.0020)	(0.7651)	(0.2584)	(0.0243)	(0.2867)
Adj. R-square	0.9086	0.6331	0.9898	0.7313	0.6352	0.9781
DW	1.1853	1.0300	1.0020	1.1621	1.2003	1.3304

Note: ** and * are significance at 1% and 5% respectively.

The estimation result reports a positive and statistically significant coefficient for trade openness for CO2 emission which means the higher the level of trade openness is, the emission of CO2 emissions. The result also shows that the magnitude of the impact of trade openness on the CO2 is not significant. This result does not provide strong evidence to suggest a strong impact of trade openness on trade in Nigeria. Studies such as Tamazian and Rao (2016) and Ahmed and Long (2021) also find evidence indicating that increase in trade openness leads to more emission. A similar result is also reported for NO2. Where trade openness has a marginal positive impact on NO2 emission. On the other hand, trade openness is seen to have a negative impact on CH4.

For GDP is a measure of economic output, we find a rather surprising result. The estimated result shows that GDP has a negative impact on CO2 emission. The result is also seen to be significant as shown by the magnitude of the parameter estimate. Specifically, it shows that a unit rise in GDP will lead to a reduction in CO2 emission amounting to 0.81. This result is counterintuitive and is in sharp contrast with the popular belief that expansion in economic output leads to more emission. However, the result can be explained by some factors. The structural political economic composition of GDP shows that the economy has been diversifying away from oil and gas and other heavy carbon emitting industry into services sectors that typically uses less carbon-intensive production techniques.

For instance, service sector such as telecommunication, banking, information technology and trade accounts for over 50% of Nigeria's GDP. Tang and Tan who posits that countries with larger industrial sector as a proportion of GDP like China will have more emission compared to countries whose greater proportion of GDP is accounted for by services.

For population, we find a positive parameter estimate which is in line with theoretical stipulation. The positive parameter estimate indicates that increasing population leads to increase emissions. It is widely expected that a higher population will lead to greater demand for energy demand and other CO2 emitting activities. Destek and Sinha (2020) and Liddle and Lung (2015) provide similar results for G-7 countries and OECD countries respectively. They explained that increase in population often lead to increase economic activities and demand for energy consumption and the attendant effect on CO2 emission. The result for urbanization diverges from popular position in the literature. The result shows a negative but statistically insignificant parameter estimate implying the existence of a weak linkage between urbanization and CO2 emission for Nigeria. Liddle and Lund (2015) posit that urbanization in some regions may shift economic activities from carbon-intensive industries toward service-oriented industries which typically has lower CO2 emissions. Hence, urbanization is some countries led to more efficient energy use and reduction in CO2 emission.

Expectedly, we find empirically consistent result for fuel consumption (FUECON) and renewable energy (RENEL). First, we find a strong positive linkage between fuel consumption and CO2 emission which corroborates previous studies such as Tamazian and Rao (2016). The result reports a positive and significant parameter estimate for fuel consumption implying that fuel consumption is a key driver of CO2 emission in Nigeria. Renewable energy consumption takes on a negative but not significant parameter estimate, showing that renewable energy mitigates CO2 emission.

Sectoral Trade Elasticities

In this subsection we investigate the impact of sectoral trade elasticities on sectoral CO2 emissions. The empirical method includes trade and manufacturing trade in different equation specification as indicated in models 1 and 2 to avoid biased estimate. Same is done for Fuel trade. Manufacturing CO2 and Fuel CO2 are employed here because they account for the largest proportion of CO2 emission in Nigeria. The result of estimation is reported in table 5 below.

To begin with, we particularly focus on the parameter estimate of trade in fuel (LOG_TRDF) in equation 2. and manufacturing trade (LOG_TRDM) in equations 3 and 4., trade openness (Log_Top) has a marginal positive impact on CO2 emission from fuel (FUE_CO2). It shows that a unit increase in trade openness will cause FUE_CO2 emission to increase by 0.0408. As expected, the result for fuel consumption (FUECON) returns a positive and statistically significant parameter estimate indicating the strong magnitude of the effect of fuel consumption on (FUE_CO2). Interestingly, Fuel-related CO2 emissions (FUE_CO2) are positively influenced by both per capita income and population size.

Table 5: Sectoral Trade Elasticities

Dependent Variable:	FUE_CO2		MAN_CO2	
	Equation 1	**Equation 2**	**Equation 3**	**Equation 4**
C	0.3014***	0.3176***	-18.5325***	-18.6577***
	0.0015	0.0019	0.0000	0.0000
LOG_TOP	0.0408		-0.0173	
	0.1754		0.9212	
LOG_TRDF		0.0514		
		0.5636		
LOG(FUECON)	0.6933***			
	0.0000			
LOG_TRDM				0.9195*
				0.0803
LOG_YMAN			0.9792*	
			0.0655	
(LOG_YPC)	0.2439	0.1911		
	0.3297	0.4514		
D(LOG(POPR)	0.1617	0.4816	1.0698***	1.0763***
	0.8273	0.5092	0.0000	0.0000
D(LOG(URBR)	-0.0941	-0.1427	-1.6086*	-1.6410*
	0.6918	0.5558	0.0921	0.0819
D(LOG(RENEL	-0.0016	-0.0215	-0.8115	-0.7888
	0.9901	0.8722	0.2442	0.2508
R-squared	0.7217	0.7033	0.6634	0.6727
Adjusted R2	0.6521	0.6292	0.5987	0.6098
D-W stat	1.8155	1.9008	1.4752	1.4452

Higher income levels and population growth contribute to increased emissions, but the effects are proportional to the elasticity values (0.2439) for income and 0.1617 for population). In model 2, under FUE_CO2, we report positive influence by both trade flows (TRDF) and per capita income (YPC). The result shows that economic activities like trade expansion and increased income levels lead to higher emissions, but the magnitude of income (0.1911) is larger than that of trade flows (0.0514).

demand. Urbanization shows an insignificant negative impact, potentially reflecting a shift toward less carbon-intensive industries. Fuel consumption is a significant driver of emissions, while renewable energy shows potential for mitigation despite its insignificant impact.

The study provides a unique perspective on the impact of GDP structure in Nigeria, where a shift toward service-oriented sectors has helped mitigate CO_2 emissions. It also highlights the mixed environmental implications of trade openness across different greenhouse gases

In the second column where the dependent variable MAN_CO2 the following result is reported. Manufacturing-related CO2 emissions increase significantly with higher manufacturing output, as shown by the strong positive coefficient for (YMAN). However, increase in manufacturing trade (TRDM) appears to have a small negative effect, potentially due to trade-induced efficiency or cleaner production practice.

The results reveal sectoral dynamics in CO2 emissions. Fuel-related emissions are driven by rising income levels (YPC) and population growth (POPR), showing that economic and demographic expansion increase energy demand. Trade flows (TRDF) have a smaller positive impact on fuel emissions, indicating limited influence. In manufacturing, emissions are strongly tied to industrial output (YMAN), with nearly proportional effects, while trade openness (TOP) shows a minor negative impact, possibly reflecting cleaner technologies or efficiency gains. This sectoral analysis underscores the role of economic activities in shaping emissions patterns and the need for targeted mitigation strategies.

CONCLUSION

This study embarked on an empirical investigation of the impact of trade openness on CO2 emission in Nigeria. The findings here indicate a nuanced relationship between trade openness, GDP, population, and CO_2 emissions in Nigeria. We specifically observe that, trade openness which is the explanatory variable of utmost interest has a marginal positive impact on CO_2 and NO_2 emissions but reduces CH_4 emissions. The surprising result of GDP reducing CO_2 emissions may well suggests the existence of a structural shift in Nigeria's economy towards service-driven, less carbon-intensive sectors. Population growth aligns with theoretical expectations, contributing to higher emissions due to increased energy (CO_2, NO_2, CH_4). These insights challenge traditional narratives and underscore the complexity of emissions drivers in a diversifying economy. Similarly, the sectoral analysis highlights the role of economic activities in shaping emissions patterns and the need for targeted mitigation strategies.

Investigating the scaling effects of renewable energy technologies, as well as the interplay between urbanization and energy use, will provide deeper insights into sustainable development pathways. Also, a broader comparative analysis to Sub-Sahara Africa can provide a more robust framework for regional policy formulation.

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