CARBON EMISSIONS AND INTERNATIONAL TRADE IN SUB-SAHARAN AFRICA: A DYNAMIC PANEL THRESHOLD ANALYSIS

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ABSTRACT

Climate change has been linked to cross-boarder trade where carbon emissions constituted a major source of environmental degradation. This study focused on carbon emssions and international trade in sub-Saharan Africa. A dynamic panel threshold model of carbon emissions (CO_2) and international trade was estimated. The result indicate the existence of threshold in CO_2 emissions for total trade, export and import in sub-Saharan Africa. The average estimated threshold in million metric tons of CO_2 emissions is 2455.29. Our result suggest that this is the emissions benchmark above which CO_2 emissions will negatively be correlated with international trade in our sample. Our finding equally support that sub-Saharan Africa's trade are CO_2 emission-laden notwithstanding the prevailing regime. The CO_2 emission threshold of import is less than that of total trade and export. This suggests that sub-Saharan African countries export more CO_2 emissions than they import. Thus, there is no evidence in support of Pollution Haven Hypothesis in sub-Saharan Africa based on our findings. We recommend that as sub-Saharan Africa strive to achieve export-led growth through expansion of its export, there is need to concentrate on green trade in order to be competitive in the international market and avoid being caught up with environmental restrictions on trade. Subsaharan African countries should learn from the experiences of industrialized world and intensify utilization of clean energy for growth and expansion. We equally recommend a balance in the global implementation of climate policies in order not to harm African economies' quest for industrialization.

Keywords: Carbon emissions, international trade, dynamic panel threshold model
JEL classification: C23, F18

1. INTRODUCTION

The nexus between environmental sustainability and economic development is at the core of global policy discourse, as encapsulated in the United Nations Sustainable Development Goal (SDG-13), which focuses on combating climate change and promoting environmental sustainability. A growing body of research highlights that as economies transition to higher income levels, the demand for improved environmental quality increases. However, the relentless pursuit of economic growth, industrial expansion, and anthropogenic activities continue to impose significant pressures on the environment. In sub-Saharan Africa (SSA), this relationship is particularly critical as the region faces unique challenges associated with climate change and environmental degradation, both of which are exacerbated by international trade dynamics.

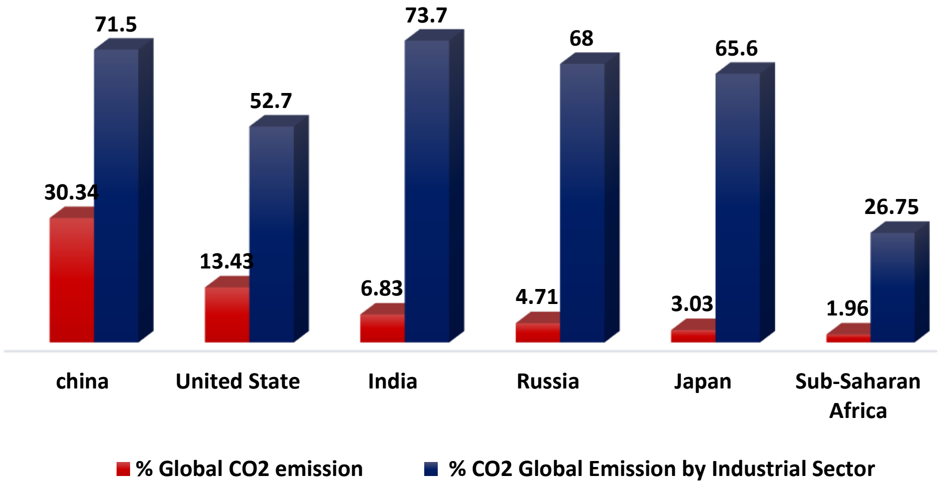
Climate change driven largely by greenhouse gas (GHG) emissions, particularly carbon dioxide (CO_2), pose severe threats to all facets of human existence. According to Dellink, et al. (2017), carbon dioxide (CO_2) constitutes approximately 75% of total GHG emissions globally, making it a primary contributor to global warming and climate-related disasters. IPCC (2022) reports that Africa is one of the most vulnerable regions, with climate impacts threatening agricultural productivity, human health, and economic stability. The urgency of addressing these climate risks has led to the prioritization of climate action in both domestic and international policy arenas, with a growing emphasis on collective efforts to mitigate the adverse effects of climate change.

International trade has emerged as a critical driver of environmental change, with significant linkages to climate change. Studies by Brenton and Chemutai (2021) reveal that approximately 25% of global CO_2 emissions are linked to international trade, as the scale and intensity of production, consumption patterns, and transportation of goods across borders contribute to heightened emissions. Wu et al. (2020) further underscore a bidirectional relationship between trade and climate change, where increased trade activities not only exacerbate emissions but are also disrupted by climate-induced infrastructure damage. Despite these global trends, SSA countries characterized by low industrial output and heavy reliance on raw material exports, contribute relatively little to global CO_2 emissions. According to Bauer and Scholz (2010), SSA accounts for less than 2% of global emissions, yet the region bears a disproportionate share of the impacts of climate-induced disruptions.

The unique position of SSA within the global trade and emissions matrix presents a paradox. According to Brenton and Chemutai (2021), industrialized nations, particularly China, the United States, and the European Union, contribute the greater share of emissions accounting for about 70% of global CO_2 emissions. However, it has been argued that many of the emissions in developed countries are driven by the consumption of goods produced in developing countries (Copeland and Taylor, 2004; Brandi,2017). The argument that most of the emissions from developing economies, including SSA, are embodied in exports to high-income countries, has affected their international trade position. This has led to increased regulatory pressures on developing nations to adopt greener production technologies. This trend has sparked contentious debates, as developing nations argue that they should not be held to the same stringent environmental standards that industrialized countries adhered to in their own development trajectories (Bauer and Scholz ,2010).

In recent years, SSA has begun to see a rise in carbonization, with emerging economies within the region contributing to global emissions at an accelerating pace. Between 2010 and 2018, the annual growth rate of emissions from 59 emerging economies, including some in SSA, was 6.2%, compared to a global average of 2% (Brenton and Chemutai, 2021). However, the region's emissions remain minimal compared to those of the major industrialized economies. Figure 1 shows the percentage contribution of global CO_2 emissions and CO_2 emissions from the industrial sector of sub-Saharan Africa and five industrialized countries.

Figure 1: Five Industrialized Countries' and Sub-Saharan Africa Emissions



Source: https://www.worldometers.info, (2022)

Figure 1 reveal that 30.34 % of global CO_2 emissions come from China while 13.43 % come from the United States. However, less that 2 percent of global CO_2 emissions come from the entire sub-Saharan Africa. In terms of CO_2 emissions by sector, Figure 1 shows that 71.5 % of China's emission came from the industrial sector while 52.7 %, 73.7 %, 68 % and 65.6 % of United States, India, Russia and Japan respectively come from their industrial sectors. However, only about 27 percent of the 2 percent global CO_2 emissions in sub-Saharan Africa come from their industrial sector. Therefore, sub-Saharan African countries are better positioned towards green industrialization and trade.

Given the limited contributions of SSA to global emissions and the region's relatively low industrial capacity, the imposition of carbon mitigation strategies modeled after those of developed nations may be premature. Brenton and Chemutai, (2021) highlights that most SSA economies remain heavily reliant on agriculture and raw material exports, sectors that are less carbon-intensive than manufacturing. However, the pressures for greener trade and production are mounting, with significant implications for SSA's trade competitiveness. Therefore, it is crucial to investigate whether there exists a threshold of CO_2 emissions that could influence trade dynamics in SSA, particularly as the region seeks to balance economic growth with environmental sustainability. The objective of this study, therefore is to examine the relationship between CO_2 emissions and international trade in SSA using a dynamic panel threshold analysis. To achieve this objective, we addressed the following questions: Is there a CO_2 emission threshold for sub-Saharan Africa? How would CO_2 emission affect sub-Saharan Africa's international trade at low (high) emissions regimes? Studies on trade and environment in sub-Saharan Africa are sparse. To the best of our knowledge, there is no study on CO_2 emissions and international trade in sub-Saharan Africa that utilized an analytical framework of dynamic panel threshold model. This constitutes a gap that this study filled. The rest of the paper is organized as follows: section 2 is literature review, section 3 dwells on methodology, section 4 is devoted to empirical result while section 5 concluded the study.

2. LITERATURE REVIEW

2.1 Theoretical Review

Globalization has heightened the quest for many countries to seek global integration. Bond et al (2005) argues that countries can transition from stagnation to rapid growth if they engage in international trade by leveraging on technology transfers and capital inflows. Many trade theories exists but not many exists in terms of trade relationship with the environment. In this study, we discussed two major trade-environment theories – the popular Environmental Kuznets Curve (EKC) and the Pollution Haven Hypothesis (PHH). The Environmental Kuznets Curve emphasize income effect of growth on the environment. This theory postulate that, at the initial growth path of an economy, environmental quality is a secondary consideration. But at high levels of income, demand for environmental quality increase. When income increases and environmental regulations drive down emissions, this result to the inverted-U shaped relationship of economic development and emissions (Copeland and Taylor ,2004; Jebli and Youssef, 2015). On the other hand, Levinson and Taylor (2008) explain that PHH is the tendency for firms in developed countries to relocate pollution-intensive industries to developing countries with less stringent environmental regulation. This makes the developing countries pollution havens. This hypothesis is closely linked to international trade as globalization permits firms to locate their operations abroad where there are cost advantages and lower environmental compliance cost. This theory highlights the basis for tightening environmental policies. In order to maintain environmental quality, countries implement stricter policies to forestall potential harmful effects of environmental unfriendly industries (Cole and Elliott,2005).

The interconnection between these two theories has triggered further debate on trade and environmental quality imbalance among different region. Following the EKC hypothesis, countries that raise their national income through trade strive to maintain higher environmental quality usually by reducing emission laden imports through taxes (Grossman and Krueger, 1993). Ironically, higher income countries shed their dirty production through international trade by exporting to countries with less stringent environmental policies. This offers an abatement mechanism in access to world markets where countries can import goods from abroad when higher pollution taxes make it more expensive at home. This implies that countries with lax environmental policy are likely to become pollution havens. Due to low level of technology and slow pace of industrialization, environmental policies in most developing countries are less stringent which potentially exposes them to cross-border emissions transfer.

2.2 Empirical Review

Literature on carbon emissions and international trade is still evolving particularly for sub-Saharan Africa. Majority of the recent empirical literature in this area focused on climate change and sectoral economic growth with quite a few focusing on trade. We reviewed selected literature on climate change, economic growth and trade. Dellink et al (2017) investigated the consequences of CO_2 emissions on international trade of OECD countries and concluded that there is need to focus more on green trade to avoid a looming environmental disaster on future trade. Asogwa et al. (2018) studied the factors that determine renewable energy use and carbon emission intensity in Sub Sahara Africa using principal component analysis. They found that population density is a major factor influencing renewable energy use while renewable energy regeneration in turn reduces carbon emission. Rahman and Vu (2020) carried out a comparative study of the relationship among economic growth, trade, urbanization, renewable energy and CO2 emissions for Australia and Canada and concluded that long-run relationships exists amongst the variables. Wu et al (2020) studied the causality between participation in global value chains, renewable energy consumption, and CO_2 emissions and found that there is existence of causality between participation in global value chains and CO_2 emissions. Agu and

Obodoechi (2021) investigated the linkage between CO2 emissions, temperature changes, productivity, and labor supply as it relates to farming in Nigeria. They found that labor supply and CO2 emissions have significant and positive effects on agricultural output in Nigeria.

Petruska et al (2021) studied the dependence of CO_2 emissions on energy consumption and economic growth in the European Union and found that the dependence of CO_2 emissions on energy consumption varies at different levels of GDP. Kahn et al (2021) investigated the long-term impact of climate change on economic activity and found that per-capita real output is negatively affected by constant changes in temperature. Sandalli (2021) utilized a panel autoregressive distributed lag model to study macroeconomic implications of climate change on Sub-Saharan Africa and revealed that countries are adversely affected by temperature variations occasioned by CO_2 emissions. Alehile et al. (2022) investigated the effect of climate change on Nigerian agricultural sector crop production in a Non-linear autoregressive distributed lag framework. Their result reveal that there is a positive relationship between increase in rainfall index and crop output while a decrease in temperature is positively related to crop production at different lag orders.

Similarly, Uzomba (2022) investigated the dynamics of free trade and export-import competitiveness in West African countries. The result of the study indicate that terms of trade significantly impact export-import competitiveness. This study did not consider the climate change component aspect of export-import competitiveness. Habibu and Ahmed (2023) studied the role of the shadow economy on the Environmental Kuznets curve hypothesis in Nigeria. They estimated a threshold regime switching model using ecological footprint as dependent variable to proxy environmental quality, GDP per capita, financial development index, percentage of informal sector output and percentage of urban population as independent variables. Their result indicate that the shadow economy is negatively related to environmental quality while financial development is positively related to environmental quality in Nigeria. Nwosu et al. (2024) studied the effect of anthropogenic global warming and insecurity on agricultural productivity in Nigeria. The proxied global warming with methane emissions and insecurity with number of terrorist attacks. Their result indicate that insecurity is negatively related to agricultural productivity while anthropogenic global warming is positively related to anthropogenic global warming.

Many of the reviewed empirical studies showed that different measures were used to proxy climate change while concentrating on non-trade variables. Most of them are country-specific studies that did not incorporate international trade dimension to GHG emissions. The present study however, considered the nexus between international trade and carbon emission in multi-country framework. None of the reviewed studies utilized a dynamic panel threshold model. This study therefore, utilized the dynamic panel threshold model to study the nexus between carbon emissions and international trade in sub-Saharan Africa.

3. METHODOLOGY

3.1 Data and sources

Table 1 shows the data and definition of variables utilized for this study while Table 2 indicate the sub-Saharan African countries included in the sample. In all, 41 countries were included in the sample. The time series data covered between 1980 and 2020 with climate and trade variables forming the core variables while macroeconomic stability and human capital variables representing the control variables.

Table 1. Data sources and definitions of variables

Variable	Definition	Source
Climate change variable		
CO_2	Total CO_2 emissions (million metric tons)	WDI
Trade variables		
TRD	Total Merchandise annual trade (US mil $)	UN Comtrade Statistics
EXP	Share of merchandise exports at current PPP measures	Penn World Table (version 10.0)
IMP	Share of merchandise imports at current PPP measures	Penn World Table (version 10.0)
Macroeconomic stability variables		
GDP	Annual percentage growth rate of GDP	WDI
EXC	Real effective exchange rate	WDI
Human capital variables		
EMP	Number of persons engaged (in millions)	Penn World Table (version 10.0)
POP	Annual population growth rate	WDI

Source: created by authors

Table 2: Sample countries

Country	Country	Country
1. Angola		28. Niger
2. Benin	15. Ghana	29. Nigeria
3. Botswana	16. Guinea	30. Rwanda
4. Burkina Faso	17. Guinea Bissau	31. Senegal
5. Burundi	18. Kenya	32. Seychelles
6. Cameroon	19. Lesotho	33. Sierra Leone
7. Central African rep	20. Liberia	34. Somalia
8. Chad	21. Madagascar	35. South Africa
9. Comoros	22. Malawi	36. Tanzania
10. Congo democratic rep	23. Mali	37. Togo
11. Congo rep	24. Mauritania	38. Uganda
12. Cote divoire	25. Mauritius	39. Zambia
13. Ethiopia	26. Mozambique	40. Zimbabwe
14. Gabon	27. Namibia	41. Gambia

Source: created by authors

3.2 Dynamic Panel Threshold Model Specification and Estimation

In this study, we adopted the dynamic panel threshold model developed by Kremer et al (2013) which is an extension of panel threshold model of Hansen (1999). The key departure of Kremer et al (2013) from Hansen (1999) is the inclusion of endogenous regressors and lags of the dependent variable. In a bid to allow for endogeneity in a dynamic setting, we adopted the cross-sectional threshold model of Caner and Hansen (2004) which permits GMM type estimator. The standard dynamic panel threshold model is specified as follows:

$$y_{it} = \mu_i + \beta_1 z_{it} I(q_{it} \leq \gamma) + \delta_1 I(q_{it} \leq \gamma) + \beta_2 z_{it} I(q_{it} > \gamma) + \varepsilon_{it} \qquad (1)$$

where subscripts $i = 1, \dots, N$ represents the countries and $t = 1, \dots T$ represent time. μ_i is the country specific fixed effect while ε_{it} is the error term which is $iid(0, \sigma^2)$. $I(.)$ is the indicator function which indicates the regime defined by the threshold variable q_{it} and the threshold level γ. z_{it} is an m-dimensional vector of explanatory variables which may include lagged values of y and other endogenous variables. z_{it} is partitioned into a subset z_{1it}, of exogenous variables uncorrelated with ε_{it} and a subset of endogenous variables z_{2it}, correlated with ε_{it}. δ_1 is the regime-dependent intercepts. Additional to the structural equation (1), the model requires a suitable set of $k \geq m$ instrumental variables x_{it} including z_{1it}. In order to eliminate country- specific fixed effects associated with panel threshold model, we followed Arellano and Bover (1995) as implemented by Kremer et al (2013) by utilizing the forward orthogonal deviations transformation. This method eliminates the fixed effects as well as serial correlation in the transformed error terms induced from first differencing. Thus, the forward orthogonal deviation transformation preserves the original distribution theory of the threshold model that is used in the static panels of Hansen (1999) and still remain valid in a dynamic context.
The forward orthogonal deviations transformation method is then given as

$$\varepsilon_{it}^{*} = \sqrt{\frac{T-t}{T-t+1}}\left[\varepsilon_{it} - \frac{1}{T-t}(\varepsilon_{i(t+1)} + \cdots + \varepsilon_{iT})\right] \qquad (2)$$

Therefore, the forward orthogonal deviation transformation ensures that the uncorrelatedness of the error terms is maintained. The estimation procedure entails determining and selecting the threshold value γ with the smallest sum of squared residuals. After $\hat{\gamma}$ is determined, the slope coefficients can then be estimated using generalized method of moments (GMM) for the previously used instruments and the previous estimated threshold $\hat{\gamma}$.
Given the objective of this study, the dynamic panel threshold model is suitable in finding the different interaction regimes of our dependent variable and regime-dependent variable.
Therefore, the dynamic panel threshold model of the impact of CO_2 emissions on international trade can be specified as:

$$TRD_{it} = \mu_i + \beta_1 CO_{2it} I(CO_{2it} \leq \gamma) + \delta_1 I(CO_{2it} \leq \gamma) + \beta_2 CO_{2it} I(CO_{2it} > \gamma) + \emptyset z_{it} + \varepsilon_{it} \qquad (3)$$

$$EXP_{it} = \mu_i + \beta_1 CO_{2it} I(CO_{2it} \leq \gamma) + \delta_1 I(CO_{2it} \leq \gamma) + \beta_2 CO_{2it} I(CO_{2it} > \gamma) + \emptyset z_{it} + \varepsilon_{it} \qquad (4)$$

$$IMP_{it} = \mu_i + \beta_1 CO_{2it} I(CO_{2it} \leq \gamma) + \delta_1 I(CO_{2it} \leq \gamma) + \beta_2 CO_{2it} I(CO_{2it} > \gamma) + \emptyset z_{it} + \varepsilon_{it} \qquad (5)$$

From equations (3, 4, 5), CO_{2it} is the threshold variable as well as the regime-dependent regressor. Initial value of dependent variable(s) -$TRD_{it-1}, EXP_{it-1}, IMP_{it-1}$ are included as endogenous variables as captured by z_{2it}. The different dependent variables are defined as: Total Trade (TRD), Export (EXP) and Import (IMP). The regime independent slope coefficients of the endogenous control variables are contained in z_{it}. The remaining control variables are contained in z_{1it}. In this study, the control variables are Employment (*EMP*), Exchange rate (*EXC*), growth rate of Gross Domestic Product (*GDP*) and growth rate of population (*POP*). δ_1 is the regime intercept.

4. RESULT AND DISCUSSION OF FINDINGS

To kick-start the result analysis, we deployed certain analytical tools in order to ascertain the relevant properties of the data utilized in this study. In Table 3, we present the summary statistics of the data while in Table 4, we present the correlation matrix. All variables are in natural logarithm except *GDP*, *POP* and *EXC* which are in their percentage/growth rates.

Table 3: Descriptive Statistics

Variables	Mean	Std. Dev.	Min	Max	Obs
EMP	0.833	1.522	-3.603	4.264	1599
EXC	-4.129	2.862	-9.193	7.145	1599
EXP	-2.389	0.992	-6.171	0.044	1599
GDP	3.683	7.073	-50.24	149.9	1599
IMP	-0.198	0.168	-2.184	-0.011	1599
CO2	7.548	1.697	3.688	13.02	1599
TRD	6.628	1.986	0.786	11.66	1599
POP	2.631	1.009	-6.766	8.117	1599

Source: computed by the authors

From the result in Table 4, it is easily observed that all the international trade variables used in this study are positively correlated with CO_2 emissions. This confirms the analysis in Figure 1. The correlation coefficients are statistically significant except that of import (*IMP*).

Table 4: Correlation Matrix

	EMP	*EXC*	*EXP*	*GDP*	*IMP*	*CO2*	*TRD*	*POP*
EMP	1							
EXC	-0.135***	1						
EXP	-0.085***	-0.015	1					
GDP	-0.046**	-0.092***	0.059**	1				
IMP	0.161***	-0.035	-0.469***	-0.108***	1			
CO2	0.632***	0.129***	0.137***	-0.005	0.004	1		
TRD	0.594***	-0.002	0.262***	0.023	-0.082***	0.895***	1	
POP	0.093***	-0.149***	0.044*	0.168***	0.092***	-0.036	0.018	1

Source: computed by the authors. We reported the correlation matrix of all the countries in our sample to save space. ***,** and * denote significance of correlation coefficient at 1%.5% and 10% respectively

In order to avoid the problem of spurious regression, the variables in our study must be stationary. Therefore, we carried out a battery of panel unit root tests to ascertain the stationarity or otherwise of the dataset for this study. We deployed unit root test developed by Levin, Lin and Chu (2002) [*LLC*] (with null hypothesis of common unit root process), Pesaran and Shin (2003) [*IPS*], Augmented Dickey-Fuller (1979) [*ADFF*], Phillip-Perron (1988) [*PPF*] unit root tests (with null hypotheses of individual unit root process). Table 5 reports these tests results at level and first difference. Some of the series are stationary at level depending on the type of test used but all the series are stationary at first difference irrespective of the test used.

Table 5: Panel unit root Test Results

Test	*EMP*	*EXC*	*EXP*	*GDP*	*IMP*	*CO2*	*TRD*	*POP*
Level								
LLC	4.945 (1.00)	-2.459*** (0.007)	-1.789** (0.03)	-10.54*** (0.00)	-2.386*** (0.00)	-3.194*** (0.00)	-0.471 (0.31)	-12.52*** (0.00)
IPS	-1.705** (0.04)	-0.272 (0.39)	-3.266*** (0.00)	-14.91*** (0.00)	-3.163*** (0.00)	-1.926** (0.00)	-1.114 (0.13)	-16.24*** (0.00)
ADFF	114.1** (0.01)	72.28 (0.66)	130.7*** (0.00)	399.1*** (0.00)	144.5*** (0.00)	123.3*** (0.00)	112.2** (0.01)	451.3*** (0.00)
PPF	315.5*** (0.00)	68.90 (0.75)	200.3*** (0.00)	699.3*** (0.00)	177.2*** (0.00)	166.1*** (0.00)	123.7*** (0.00)	93.75 (0.17)
First difference								
LLC	31.56*** (0.00)	-8.322*** (0.00)	-20.28*** (0.00)	-27.43*** (0.00)	-20.45*** (0.00)	-19.13*** (0.00)	-18.79*** (0.00)	-12.89*** (0.00)
IPS	-9.592*** (0.00)	-15.26*** (0.00)	-25.46*** (0.00)	-36.82*** (0.00)	-26.01*** (0.00)	-22.18*** (0.00)	-22.14*** (0.00)	-16.79*** (0.00)
ADFF	254.7*** (0.00)	387.1*** (0.00)	712.6*** (0.00)	1069.3*** (0.00)	731.9*** (0.00)	608.1*** (0.00)	603.6*** (0.00)	468.5*** (0.00)
PPF	407.2*** (0.00)	624.1*** (0.00)	1247.4*** (0.00)	1134.9*** (0.00)	1244.6*** (0.00)	1021.6*** (0.00)	981.5*** (0.00)	249.3*** (0.00)

Source: computed by the authors. Probability value are in parentheses. ***,** and * denote significance at 1%,5% and 10% respectively

In order to confirm the existence of longrun relationship in our panel data, we carried out two panel cointegration tests a la Pedroni (2004) and Kao (1999). Both tests have null hypothesis of no cointegration among the series. The results of the different test statistics are presented in Table 6. Two of the Pedroni panel statistics and one of the group statistics are statistically significant while the Kao ADF-statistic is statistically significant. We therefore reject the null hypothesis of no cointegration and conclude that our data series share longrun relationship. This further permits the estimation of a dynamic panel threshold model.

Table 6 :Panel Cointegration Test

Pedroni Cointegration Test	Panel Statistics	Group Statistics	Kao Cointegration Test
V.statistic	1.246 (0.80)	---------	*ADF* statistic
Rho-statistic	4.115 (0.78)	3.382 (0.99)	-2.555*** (0.00)
PP-statistic	-1.024*** (0.00)	-5.994*** (0.00)	
ADF-statistic	-2.298***	-2.517***	

	(0.00)	(0.00)	

Source: computed by the authors - Null hypothesis: No cointegration. P-values are in parantheses.***,** and * denote significance at 1%,5% and 10% respectively.

4.1 Dynamic Panel threshold Result.

In this study, we relied on the model developed by Kremer et al. (2013) in order to establish the existence of threshold effect on international trade and CO_2 emissions. We estimated three dynamic panel threshold models using total trade, export and import respectively as dependent variables while maintaining CO_2 emissions as the threshold indicator. This enabled us to capture the asymmetric nonlinearity in the relationship between total trade, export and import in our sample in relation to CO_2 emissions. The results of the estimated models are presented in Tables 7 – 9. The upper section of the Tables shows the estimated CO_2 emissions threshold in log form (millions metric tons) as well as the 95 percent confidence interval. The middle section reports the regime-dependent coefficients of CO_2 emissions on the chosen specific trade variable. That is, $\hat{\beta}_1$ and ($\hat{\beta}_2$) shows the marginal effect of CO_2 emissions on trade (total trade, export and import) in the low (high) regime. Specifically, the low regime corresponds to the values of the estimated transition variable, CO_2 emissions, that is below the estimated threshold value while the high regime corresponds to the values of the estimated transition variable, CO_2 emissions that is above the estimated threshold value. The lower part of the tables presents the estimated coefficients of the covariates at both regimes. Table 7 presents the result of the dynamic panel threshold model where the dependent variable is total trade (*TRD*) and the threshold variable is total CO_2 emissions (CO_2). From this model, the result reveal that the threshold value is 8.096 (3281.2 Mt) and it is statistically significant which implies that we reject the null hypothesis of no threshold effect in our sample. Both regime-dependent coefficients are plausibly signed. This threshold value reveals the turning point where CO_2 emissions can positively or negatively influence trade. The result of Table 7 reveals that the estimated marginal effect $\hat{\beta}_1$ = 0.3101 implies that CO_2 emissions is positively related to total trade in the low regime while the estimated marginal effect $\hat{\beta}_2$= -0.7464 implies that CO_2 emissions is negatively related to total trade in the high regime. This finding suggests a decreasing effect on trade as CO_2 emissions increases. The falling trade equally suggest strict regulation by trading partners to high emission-embodied goods (Copeland and Taylor,2004). At both regimes, the estimated marginal effects are statistically insignificant. This implies that if CO_2 emissions increase by 1 percent, in the longrun international trade will increase by about 0.3 percent in the low regime. In the high regime, if CO_2 emissions increase by 1 percent, in the longrun international trade will decrease by about 0.74 percent. Again, the negative effect of CO_2 emissions at higher regime is bigger in magnitude than the low regime. This means that initial growth in international trade in sub-Saharan Africa can be achieved at lower levels of CO_2 emissions until the threshold of 3281.2 Mt of emission is reached ceteris paribus. Further growth drive will come at a cost of environmental degradation which will lead to negative growth in total trade. This result lays credence to the scale effect and the inverted U-shaped (EKC of Trade) in sub-Saharan Africa (Grossman and Krueger,1993).

Table 8 reports the result of the dynamic panel threshold model when the dependent variable is Export (*EXP*). The result reveal that the threshold value is 8.505 (4939.4 Mt) which is statistically significant. Again, we reject the null hypothesis of no threshold effect in our sample.

However,

Table 7 : Dynamic Panel Threshold – Trade Dependent Variable (CO_2-Threshold)

Threshold Variable		Estimated threshold	95% Confidence Interval
$\hat{\gamma}$		8.096*** (3281.2)	[7.252 - 8.940]
Impact of CO_2 on Trade			
	Below the threshold		Above the threshold
	$\hat{\beta}_1$		$\hat{\beta}_2$
	0.3101 [0.2455]		-0.7464 [0.7976]
Impact of covariates on Trade			
TRD_{it-1}	0.3488** [0.1581]		0.3984 [0.3514]
GDP	0.0037 [0.0031]		0.3716*** [0.0048]
POP	0.1805* [0.1013]		-0.4426* [0.2347]
EXC	.01342 [0.1144]		0.1653** [0.0813]
EMP	1.967*** [0.6874]		-0.8231*** [0.1821]
$\hat{\delta}$			4.912 [6.896]
Observations			1591
N			41
T			39

Source: computed by the authors. Note: values in [ ] are the standard errors/confidence interval while the value in ( ) is the threshold in thousand metric tons. ***,** and * denote 1%,5% and 10% significant respectively.

Table 8 reveal that the estimated marginal effect of $\hat{\beta}_1$ = -0.4595 implies that CO_2 emissions is negatively related to export in the low regime as well as in the high regime with estimated marginal effect of $\hat{\beta}_2$= -2.7558. This implies that if CO_2 emissions increase by 1 percent, in the longrun export will decrease by about 0.5 percent in the low regime and about 2.8 in the high regime. The absolute size of CO_2 coefficients suggest that it may be more severe to export if CO_2 emissions get too high. This may be counterintuitive to export-led growth strategy in the absence of stringent environmental regulations. At high regime, the estimated marginal effect is statistically significant and the marginal effect is more than five times the effect in the low regime. This result suggests that attempt to grow the size of export in international trade for sub-Saharan Africa beyond the threshold of 4939.4 million metric tons without green production technology will lead to negative effect on export at both regimes. This finding supports the claim of Brenton and Chemutai (2021) that sub-Saharan Africa's trade is emission-embodied notwithstanding the regime. The negative effect suggests strict trade barriers on sub-Saharan Africa's export. The emission threshold is equally higher than that of total trade which suggest lack of green trade in terms of scale of production, composition of output and technique of production. As sub-Saharan Africa strive to achieve export-led growth through expansion of its export, there is need to concentrate on green trade in order to be competitive in the international market and avoid being caught up with environmental restrictions on trade.

Table 8: Dynamic Panel Threshold – Export Dependent Variable (*CO_2*-Threshold)

Threshold Variable		Estimated threshold	95% Confidence Interval
$\hat{\gamma}$		8.505*** (4939.4)	[7.356 - 9.654]
Impact of CO_2 on Export			
	Below the threshold		Above the threshold
	$\hat{\beta}_1$		$\hat{\beta}_2$
	-0.4595 [0.3881]		-2.7558** [1.156]
Impact of covariates on Export			
EXP_{it-1}	-0.8416*** [0.2716]		1.913*** [0.236]
GDP	0.0013 [0.0013]		0.0113 [0.0084]
POP	0.0935 [0.0598]		0.2137 [0.5678]
EXC	0.3619*** [0.0911]		0.0296 [0.1432]
EMP	3.791*** [0.4931]		-0.2918 [0.5675]
$\hat{\delta}$			29.648*** [9.439]
Observations			1591
N			41
T			39

Source: computed by the authors. Note: values in [ ] are the standard errors/95% confidence interval while the value in ( ) is the threshold in thousand metric tons.***,** and * denote 1%,5% and 10% significant respectively.

In Table 9, the result of the dynamic panel threshold model where the dependent variable is Import (*IMP*) is presented. The estimated threshold value of 6.818 (914.2 Mt) is equally statistically significant which signifies the existence of threshold effect in our sample. Both regime-dependent coefficients are plausibly signed. Table 9 shows that the estimated marginal effect $\hat{\beta}_1$ = 0.2071 implies that CO_2 emissions is positively related to import in the low regime whereas in the high regime, estimated marginal effect $\hat{\beta}_2$ = -0.3988 implies that CO_2 emissions is negatively related to import. This implies that if CO_2 emissions increase by 1 percent, in the longrun import will increase by about 0.2 percent in the low regime while at high regime, import will decrease by about 0.4 percent. At both regimes, the estimated marginal effects are statistically significant. This finding supports the notion that low emission-embodied imports cause less environmental damage while the reverse is the case for high emission-embodied imports (Copeland and Taylor,2004). More so, the CO_2 emissions threshold of import is less than the CO_2 emissions threshold of both total trade and export. In other words, sub-Saharan African countries export more emissions than they import. Thus, there is not enough evidence to support Pollution Haven Hypothesis in sub-Saharan Africa (Cole and Elliott,2005; Levinson and Taylor,2008)).

Table 9: Dynamic Panel Threshold – Import Dependent Variable (CO_2-Threshold)

Threshold Variable	Estimated threshold	95% Confidence Interval
$\hat{\gamma}$	6.818*** (914.2)	[5.279 - 8.356]
Impact of CO_2 on Import		
	Below the threshold	Above the threshold
	$\hat{\beta}_1$	$\hat{\beta}_2$
	0.2071** [0.0969]	-0.3988*** [0.1123]
Impact of covariates on Import		
IMP_{it-1}	0.0245 [0.2004]	0.3675** [0.1932]
GDP	0.0002 [0.0004]	-0.0135*** [0.0004]
POP	-0.0223 [0.0458]	-0.1879*** [0.0534]
EXC	-0.486* [0.0276]	0.0690* [0.0351]
EMP	-0.3112*** [0.113]	0.3131*** [0.0737]
$\hat{\delta}$		3.7001*** [0.8764]
Observations		1591

N	41
T	39

Source: computed by the authors. Note: values in [ ] are the standard errors/confidence interval while the value in ( ) is the threshold in thousand metric tons. ***,** and * denote 1%,5% and 10% significant respectively.

The findings from the dynamic panel threshold models reveal that CO_2 emissions is consistently negatively related to trade in the high regime irrespective of the trade indicator used as the dependent variable. From the three estimated models, the average threshold value is 7.806 which is within the lowest and highest confidence interval [5.279 – 9.654] presented in the three models. The average estimated threshold in million metric tons is 2455.29. Our result suggest that this is the emissions benchmark above which CO_2 emissions will negatively be correlated with international trade in our sample. The result of the impact of the covariates in the estimated models are presented in the lower section of each table. In Table 7, the coefficients of initial trade (TRD_{it-1}), growth rate of GDP and Real effective exchange rate (*EXC*) are positively related to total trade both in the low and high regimes. While estimated coefficient of initial trade is statistically significant at the low regime, estimated coefficients of growth rate of GDP and exchange rate are statistically significant at the high regime. However, the estimated coefficients of population growth rate (*POP*) and employment (*EMP*) are positively related to total trade in the low regime but negatively related to trade in the high regime and they are both statistically significant at both regimes. In Table 8, the coefficients of initial trade (EXP_{it-1}), is negatively related to export in the low regime but positively related to export in the high regimes and statistically significant at both regimes. The estimated coefficients of growth rate of GDP, population growth rate and exchange rate are positively related to total export at both regimes. In Table 9, the coefficients of covariates are all statistically significant in the high regime even though the estimated coefficients of growth rates of GDP and population are negatively related to import at high regime.

5. CONCLUSION AND POLICY RECOMMENDATIONS

Climate change pose diverse threat to nations of the world and has recently attracted a lot of research attentions. This study focused on the impact of CO_2 emissions on international trade in subsaharan Africa with the objective of ascertaining if emissions threshold exist in relation to trade. We estimated a dynamic panel threshold model on CO_2 emissions and trade variables in a sample of 41 sub-Saharan African countries spanning between 1980 and 2020. We included other covariates that are related to both trade and climate change as control variables. Our result shows that threshold exist in CO_2 emissions for total trade, export and import in sub-Saharan Africa and that the relationship between trade and CO_2 emissions in sub-Saharan African is non-linear. The average estimated threshold in million metric tons is 2455.29. Our result suggest that this is the emissions benchmark above which climate change will negatively be correlated with international trade in our sample. Our findings support that sub-Saharan Africa's export are emission-laden notwithstanding the regime. The emission threshold of import is less than the emission threshold of both total trade and export. This suggests that sub-Saharan African countries export more emissions than they import. Thus, there is no evidence to support Pollution Haven Hypothesis in sub-Saharan Africa. The emission threshold in export is higher than that of total trade suggesting lack of green trade in terms of scale of production, composition of output and technique of production. Emission-embodied component of Africa's export is higher than that of import which indicate lack of export diversification in manufactured goods. We recommend that as sub-Saharan Africa strive to achieve export-led growth through expansion of its export, there is need to concentrate on green trade in order to be competitive in the international market and avoid being caught up with environmental restrictions on trade. Africa should learn from the experiences of industrialized world and intensify utilization of clean energy for growth and expansion. We equally recommend a balance in the global implementation of climate policies in order not to harm African economies' quest for industrialization.

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