Does trade openness increase CO2 emissions in Africa? A revaluation using the composite index of Squalli and Wilson

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Abstract

The purpose of this study is to provide new evidence on the relationship between trade openness and carbon dioxide (CO2) emissions in Africa. Based on recent data and an uncommon and more informative composite indicator of trade openness proposed by Squalli and Wilson (2011), we use an augmented Stochastic Impact by Regression on Population, Affluence and Technology (STIRPAT) model. Empirical evidence using the Two Stage Least Square estimation (2SLS) validates the "pollution haven" hypothesis and shows that trade openness increases CO2 emissions in Africa. However, the elasticity varies greatly depending on the different measures of trade openness used. Moreover, we find that trade openness is associated with an increase in CO2 emissions in North Africa, South Africa and West Africa, but rather has a negative effect on CO2 emissions in East Africa and in Central Africa. Furthermore, the quantile regression approach shows that the effect of trade openness is increasing on the Q10th, Q25th, Q50th, and Q75th quintiles, but decreasing at the Q90th quintile, thus highlighting the "scale effect". The results obtained are robust even when using other indicators of environmental quality.

JEL classification: F18; F64; N57; N77; Q56.

1. Introduction

For several decades, the desire to improve the living conditions of their populations has led African economies to establish trade partnerships with each other and with the rest of the world. Whether it concerns Free Trade Areas (FTAs), Regional Economic Communities (RECs) or even simple bilateral trade partnerships, the opening of these economies to foreign trade is not always without environmental implications (Copeland and Taylor, 2004; Frankel and Rose, 2005; Managi et al., 2009; Gozgor, 2017; Opoku-Mensah et al., 2021). Thus, the issue of climate change as well as its implications for African countries has attracted a lot of attention from researchers in recent years (Acheampong et al., 2019; Acheampong and Dzator, 2020). Moreover, the natural resource wealth of most of these economies has opened them up to foreign trade and foreign investment which contributes greatly to the growth of their respective economies (World Bank, 2020; Sun et al., 2020). We also cannot ignore the fact that intra-African trade has developed enough, particularly with the General Agreement on Tariffs and Trade (GATT) and the establishment of a Continental Free Trade Area (ACFTA) with the aim of facilitating trade between member countries with high expectations of gains in terms of trade in goods and services as well as in terms of social and environmental outcomes (Awad, 2019; Sun et al., 2020).

Regarding environmental protection, a considerable part of global funding for climate change research has been allocated towards the African continent (Overland et al., 2022), with a focus on poorer and less developed countries (Fonta et al., 2018) especially since the continent is home to the largest share of the population most vulnerable to climate change (Bond, 2014). Yet, paradoxically, Africa is the continent that has contributed the least to the causes of current climate change (Busby et al., 2014; Shukla et al., 2019). This is likely related to the trade relations that the continent has with the rest of the world. For example, the volume of inward foreign direct investment in sub-Saharan Africa has increased from only $1.16 billion in 1990 to over $73.65 billion in 2021 (World Bank, 2022), thus characterizing the strong growth dynamic in which are the African economies. However, Lindmark (2002) and Mahmood et al. (2020) point out that during the early stages of a country's development, there is usually a large increase in carbon emissions. One of the explanations for this high rate of emissions is often the fact that these economies tend to relax constraints and taxes against the entry of companies and goods that are sources of pollution, in favor of internal productivity growth and job. Several studies to date point out that the tax on carbon emissions is an effective instrument to fight against environmental degradation (see Baumol and Oates, 1971; Köppl and Schratzenstaller, 2022), especially since many African countries mainly depend on imported products such as electronic waste and second-hand products from developed countries (Dauda et al., 2021).

Moreover, some authors agree on the fact that the fight to reduce CO2 emissions does not necessarily involve increasing protectionist measures or import taxes, but also increasing the domestic price of fuels and the introduction of taxes to limit the consumption of fossil fuels in order to encourage the consumption of non-polluting energies. However, the latter approach could cost more in terms of productivity and may instead reduce economic activity (Hogan and Jorgenson, 1991; Grubb et al., 1993; Glanemann et al., 2020), given that African countries are not yet shining in terms of adoption of renewable energy or green technologies (UNCTAD, 2023). However, the challenges to date are clear: the decarbonization of African economies, which will have to be resolved sooner or later, implies acting quickly by revising upwards the competitiveness in terms of new energy technologies and by encouraging a green industry, which involves seizing the opportunities offered by green growth and minimizing the risks of CO2 emissions (Saidi and Omri, 2020).

Studies linking trade openness and CO2 emissions (see Hossain, 2011; Shahbaz et al., 2013, 2017; Acheampong and Dzator, 2020; Dauda et al., 2021; Udeagha and Ngepah, 2022) attempt to propose solutions that can keep emissions relatively low compared to the maximum acceptable industrial level of 2°C. However, efforts still need to be made because even if the industrial sector is still weak, the transport sector in African economies consumes even more energy and is very polluting (World Bank, 2020). In addition, production growth, urbanization and population growth have not helped in this fight because these latter factors tend to increase CO2 emissions in Africa considerably (IEA, 2019; Acheampong et al., 2021; Djeufack et al., 2023). Indeed, despite the abundance of literature on the subject, the results reached by the studies remain mixed. On the one hand, some point to the existence of a statistically significant effect of trade openness on CO2 emissions in Africa (Shahbaz et al., 2013; Adams and Opoku, 2020; Tawiah et al., 2021; Adams and Kaffo, 2022). On the other hand, authors find no causality between the two variables (Zerbo, 2017; Yameogo et al., 2021). Even when there is a significant influence as encountered in most cases, the signs obtained lead to a real maze. Attempts at explanation highlight the fact that this divergence in results depends on both the methods of analysis used and the measures adopted (Ho and Iyke, 2019; Mignamissi and Nguekeng, 2022). Moreover, the study periods considered by the authors are most often different as well as the samples, which also explains why the results obtained in short-run analyzes on a sample differ from those in the long run.

In this work, we reassess the relationship between trade openness and CO2 emissions in the African context, using a less common and more informative measure. It is the composite measure of trade openness calculated following the methodology proposed by Squalli and Wilson (2011). It is a two-dimensional measure that takes into account not only the contribution of individual countries to world trade[4] (Trade Share), but also their interactions and interconnections with the rest of the world (World Trade Share). We then use robust estimation techniques for the empirical specifications, including the Ordinary Least Squares

(OLS), then the Generalized Least Squares (GLS) estimator as well as the Driscoll-Kraay specification whose coefficients are more robust in the presence of heteroscedasticity, autocorrelation and any form of spatial and temporal dependence (Driscoll and Kraay, 1998; Hoechle, 2007). Based on the assumption that the relationship between trade openness and CO2 emissions could be endogenous (Frankel and Rose, 2005; Adams and Apoku, 2020; Mignamissi and Nguekeng, 2022), we apply the Two Stage Least Squares (2SLS) estimator with internal and external instrumentation. For sensitivity analyses, we first use alternative measures of trade openness. Subsequently, we assess the effect of the presence of natural resources and, given that historical and cultural factors could also influence environmental outcomes (Acemoglu et al., 2001; Álvarez-Díaz et al., 2011; Koehrsen, 2015; Acheampong et al., 2021; Wang and Luo, 2022), we perform a sensitivity with the aim of seeing if religion, ethnicity, and spoken language can explain environmental outcomes in African countries. Finally, we appreciate the heterogeneity of the relationship across the five main sub-regions of Africa. The study shows that, overall, trade openness increases CO2 emissions in Africa. These results confirm the pollution haven hypothesis. Our results are robust to changing environmental quality indicators, using different specifications of Quantile Regression (QR), and changing the instrumentation approach. Taken together, these results provide the basis for sound and specific policy recommendations for African economies.

The rest of the paper is structured around 5 sections. Section 2 presents a brief overview of the literature. Section 3 presents the methodological approach and the data. Section 4 highlights the results of the study and their discussion. Section 5 presents the sensitivity and robustness analyses. Finally, section 6 is devoted to the conclusion and recommendations.

2. Literature review

2.1. Theoretical overview

Theoretical work has succeeded in identifying a series of hypotheses linking trade openness and environmental quality, but empirical verifications of these hypotheses have not only lagged behind, but also failed to lead to conclusive results. To understand the cause of these differences, it is important to identify the mechanisms by which changes in the economy are related to environmental outcomes. To do this, it is possible to start from the three-effects model conceptualized by Grossman and Krueger (1993), namely the scale effect, the composition effect, and the technical effect, and subsequently highlight the halo and pollution haven hypotheses (Antweiler et al., 2001; Frankel and Rose, 2002; Copeland and Taylor, 2004; Copeland, 2013) to show this connection. We summarize on a case-by-case basis, the different mechanisms through which trade openness affects CO2 emissions and the associated signs in Fig. 1.

First, as shown in Fig. 1, the opening of economies to foreign trade is generally followed by an intensification of economic activity, which leads to high consumption of fossil fuels in industries, sources of pollution. Moreover, since the expansion of trade requires significant means of transport to ensure the mobility of goods between the different borders, this further increases CO2 emissions, especially when economies use traditional means of transport (Grossman and Krueger, 1993; Antweiler et al., 2001; Copeland and Taylor, 2004). The scale effect is thus realized when the growth of economic activities following the opening up of trade in the country leads to strong demand for both raw materials and energy, which leads to a high intensity of CO2 emissions if the production process remains unchanged (Grossman and Krueger, 1993, 1995). Second, the pollution haven hypothesis highlights the fact that in developing countries there are lower environmental standards that attract polluting and energy-intensive industries from developed countries. Developing countries thus become a “pollution haven” for developed countries. On the other hand, if the environmental rules are strict, trade openness will rather lead to a reduction in polluting gas emissions (Chen et al., 2022). Indeed, for several decades, economists have emphasized the introduction of taxes on CO2 emissions as the main tool of environmental policies (Baumol and Oates, 1971; Speck, 2017). It is indeed a specific form of environmental taxes that include all taxes fixing the price of individual activities harmful to the environment in order to internalize their negative impacts. Moreover, the composition effect results from the fact that trade liberalization leads countries to specialize in sectors where they have a comparative advantage (Copeland and Taylor, 2004). In the case of African countries, the composition effect of trade openness could most lead to strong environmental degradation because their specialization itself depends on factors related to the relaxation of environmental constraints (Kahuthu et al. al., 2006; Ertugrul et al., 2016).

Third, trade openness can lead to a technical effect in production processes and allow the "pollution halo" hypothesis to be verified with an improvement in the quality of the environment. This occurs when the opening of trade barriers encourages the entry of generally cleaner and environmentally friendly modern technologies. The incorporation of these new production technologies can also be a source of massive production, thus leading to a high level of growth that can provide countries with a certain autonomy and confidence in the application of restrictive measures against the entry of polluting technologies and companies. Indeed, the idea that trade openness can reduce environmental degradation has long been supported by authors such as Frankel and Rose (2002) whose work is a frame of reference for understanding the mechanisms through which trade openness contributes to reducing CO2 emissions.

2.2. Empirical review

The empirical literature on the link between trade openness and CO2 emissions mirrors the theoretical conceptualizations presented in the previous section. Although it almost always validates the existence of a significant causality, it is not decisive with respect to the sign. This discrepancy in results depends not only on the methods, samples, or study areas, but also on the measures used (Cherniwchan et al., 2017; Zhang et al., 2017; Shahbaz et al., 2017; Ho and Iyke, 2019). For example, evidence on the existence of a positive relationship has been provided by work such as that of Adams and Opoku (2020) who employed the system generalized method of moments on data of Sub-Saharan African countries over the period 1995–2014. They find that international trade increases CO2 emissions. Their results are robust across different trade compartments and different measures of carbon dioxide emissions. Using data from 8 sub-Saharan African countries, Vural (2020) also finds that trade openness significantly increases CO2 emissions. In a more specific framework for a large sample of African countries, Adams and Kaffo (2022) find a strong positive and direct relationship between economic integration and environmental degradation.

Regarding the negative effect, Shahbaz et al. (2013) show from an ARDL model that trade openness reduces pollution in South Africa. They explain this result by the fact that South Africa has a strong absorptive capacity for foreign investment, flexible regulations in terms of environmental protection and strict control in terms of production technologies. Additionally, Avom et al. (2020) showed from a panel of 21 sub-Saharan African countries that trade openness reduces CO_2 emissions. From the perspective of a long-term analysis, Sun et al. (2020) found that trade openness (sum of imports and exports measured in current USD) has a negative impact on CO_2 emissions in a sample of 18 sub-Saharan African countries. They also verify and approve the existence of an environmental Kuznets curve (EKC). Recently, a study conducted on a set of 50 African countries by Tawiah et al. (2021) aimed to see what are the environmental repercussions of the particular case of Sino-African trade. Using a regression through the Fully Modified Ordinary Least Square (FMOLS), they conclude that imports and foreign direct investment reduce CO_2 emissions.

On the other hand, using a sample of 9 African countries, Dauda et al (2021) find rather mixed results. On the one hand, they validate the pollution haven hypothesis and show that trade openness accelerates CO_2 emissions in some African countries such as Mozambique and South Africa. On the other hand, they find that in Kenya and Algeria trade openness reduces CO_2 emissions. They thus highlight the pollution halo hypothesis, justified by the fact that international trade could be followed by advanced production methods that respect the environment. Within the same analytical framework, Udeagha and Ngepah (2022a) focus on the case of South Africa and show firstly, using recent data (1960–2020), that trade openness deteriorates environmental quality. Second, they validate the hypothesis of the existence of an EKC while showing that the scale effect increases CO_2 emissions, while the technical effect contributes to decrease them. However, there are studies that do not validate the existence of a significant causality between trade openness and environmental degradation. The study by Adebayo et al (2021) is one of the most recent examples. Their empirical results show that trade openness, measured by the economic globalization index, has no influence on CO_2 emissions. Indeed, they reaffirm the results obtained by Yameogo et al. (2021) who also used as a measure of openness, the economic globalization index of 20 sub-Saharan African countries and found no significant effect on either CO_2 or N_2O emissions. Finally, the study that used the special case of the trade openness measure as a share of trade is that of Zerbo (2017) with a sample of 14 African economies over the period 1971–2011. He also finds no significant effect between trade openness and environmental degradation.

2.3. Literature gap

The empirical field on the relationship between trade openness and environmental degradation has nevertheless shown some shortcomings, despite the scope and diversity of work on the subject. The present investigation does not pretend to fill them all, no. Those identified and on which we add modest value are the following: First, to the best of our knowledge, no study has yet been conducted in Africa to examine the deep relationship between trade openness and CO_2 emissions for shed light on the precise mechanisms by which this link might operate, while using a broad sample of African countries. Second, previous studies do not agree on the sign of causality, largely because very little research has taken into account the fact that realities could be different within Africa itself, from one sub-region to another. Third, the measures of trade openness have not always met with unanimous support in the studies, which sometimes leads either to contradictory results or to conclusions that are over or undervalued because the latter do not take into account the real share of the countries considered in the world trade. Fourth, this work makes an experimental contribution to the literature by examining the effect of trade openness on the rate of carbon dioxide emissions using sophisticated panel data estimation techniques. Fifthly, empirical studies on the relationship between trade openness and environmental degradation in Africa have rarely considered in their analysis other polluting gases such as nitrous oxide (N_2O), fine particles ($PM_{2.5}$) and methane (CH_4).

2.4. Some stylized facts

The consequences of the 2008 economic crisis were not only financial, as it also led to a remarkable slowdown in trade throughout the world. In this regard, the African continent has not escaped it, as shown in the right-hand compartment of Fig. 2. This is explained by the fact that the crisis has led to the restriction of trade credits and the deterioration of the guarantees, which are essential for exports, thus limiting international trade and making African economies increasingly fragile because they are mainly importers of manufactured goods, even if this is not very visible on the evolution of their GDP (Bussière et al., 2013). However, even after 2012, there has been a certain decrease in the openness rate of African economies, related to a global trend break in international trade characterized by mistrust and the increasing use of protectionist measures (Jean, 2015; Crozet et al., 2015). However, it can be seen in the left-hand compartment of Fig. 2 that the growth of CO_2 emissions also experiences a trend break at a similar date to that of trade opening. This is probably due to the fact that the decrease in trade openness of African countries that led to a decrease in transport and industrial activity, and thus a reduction in polluting gases. This slowdown, as well as the downward trend in the rate of CO_2 emissions, could be explained not only by international clauses on environmental protection, but also by the development of environmentally friendly technological innovations. As shown by Dauda et al. (2021), innovations have negative effects on CO_2 emissions by using renewable energies instead of fossil fuels.

The previous observation is all the clearer when we see in Fig. 3 that there is a very strong positive correlation between trade openness and carbon dioxide emissions. This remains true regardless of the measure of trade openness considered. Indeed, even if the correlation remains positive, we still notice that the position of countries changes depending on the measure of trade used. For example, between the composite trade openness index (CTS) and the trade share (TS), the respective positions of Equatorial Guinea and South Africa are completely swapped.

In order to better understand this phenomenon, and to shed more light on it, we have developed in Table A3 in the appendix, the ranking of the countries in our sample according to these two measures of trade openness. We find that Madagascar for example occupies the first position while Nigeria occupies the eighth according to the CTS indicator. Yet under the classic TS approach, the positions are reversed with Nigeria in first place and Madagascar in twenty-ninth. This can lead to interpretations that do not reflect reality, especially since there is no doubt that Madagascar's level of openness to the rest of the world is higher than that of Nigeria due to its high exposure to the sea. Further on, we show (see Fig. 4) that the evolutions of these trade openness indicators did not always follow the same trend, including the KOF Trade Globalization Index (KOFTrGI) and the share of individual countries' trade in world trade (WTS).

3. Methodology and data

3.1. Theoretical specification of the model

In view of the limitation encountered in the work on trade openness and environmental quality, mainly the lack of convergence on a single theoretical model studying the effects of human activities on the environment. We adopt an empirical specification based on the STIRPAT model, which is a stochastic form of the IPAT (Impact of Population, Affluence and Technology) model.

The IPAT model was theoretically developed by Ehrlich and Holdren (1971) and describes the impact of human activities on the environment. This model is used to evaluate the impact of population, wealth and technology on the environment. IPAT shows that the environmental impact (I) is a multiplication of three basic driving forces (I = PxAxT). These three driving forces are population size (P), wealth (A, economic activity per capita) and technology (T). Although the IPAT model is a very useful theoretical framework, it does not allow for hypothesis testing and is inflexible in the sense of proportionality restrictions between variables. To overcome this shortcoming, Dietz and Rosa (1997) developed a stochastic version of the IPAT model, called STIRPAT. The STIRPAT model allows for the visualization of the stochastic effects of population, wealth and technology on the environment using regression methods (York, et al., 2003). The general form of the STIRPAT model is given by the following equation:

$$I_i = e^a P_i^b A_i^c T_i^d e^{\epsilon_i}$$

1

Taking the natural logarithm of both sides and assuming panel specification, we have:

$$ln\left(I_{it}\right) = a + bln\left(P_{it}\right) + cln\left(A_{it}\right) + dln\left(T_{it}\right) + \epsilon_{it}$$

2

Where a is the constant; b, c and d are elasticities associated with P, A and T, respectively; ϵ_{it} is the error term. The subscript i indicates that these quantities (I, P, A and T) vary across observation units; t indicates the year. Eq. (2) presents the linear relationship between population, wealth, and technology. The factor T cannot be associated with technology alone in the STIRPAT model. Moreover, it represents everything other than population and affluence (York, and al., 2003). In this study, the relationship between emissions and urbanization is investigated. Additional factors can be introduced into the basic STIRPAT model as components of the technology term (York, and al. 2003, Poumanyvong and al., 2010; Martinez-Zarzoso and al., 2011).

3.2. Empirical model and data

In this paper, we adopt the following empirical specification:

$$CO2_{it} = \alpha + \beta CTS_{it} + Z_{it}^{\prime}\varphi + \epsilon_{it}$$

3

$CO2$ is a measure of environmental quality, measured by polluting per capita emissions of CO2, CTS the index of trade openness constructed from the methodology of Squalli and Wilson, (2011), and Z is a set of control variables such as industrialization, GPD per capita, Domestic credit (financial development), Agriculture as well as population. ϵ_{it} is an error term. i and t describe individual and temporal dimensions.

The data used in this study are mainly from the World Bank Development Indicators (WDI). Our study covers a sample of 41 African countries (see Table A3 in the Annexes) over the period 1995–2019 due to historical constraints on the one hand and technical constraints on the other. The historical constraint is the starting year 1995, which marks a major event in the integration of economies with the advent of the World Trade Organization and the ratification of trade agreements by the African countries. The technical constraint is due to the availability of data, which stops for most countries in 2019.

3.3. Construction of the trade openness measure

Squalli and Wilson (2011) start from the definition of the ratio of trade share and the weight of country i in world trade (world trade share). Let X and M respectively be the exports and imports of a given country. The first dimension of trade openness of country i is noted as follow:

$$TS_i = \frac{(X+M)_i}{PIB_i} \text{withAvec} 0 \leq TS_i \leq \infty$$

4

The second dimension of trade openness point out the relative contribution of a country in the total world trade. If we consider a set of countries, $j = 1, 2, 3, \ldots, n$, where $i \in j$, then the share of country i in the world trade can be expressed as:

$$WTS_i = \frac{(M+X)_i}{\sum_{j=1}^{n}(M+X)_j}$$

5

Taking into account these two previous dimensions (WTS and TS), we thus obtain the composite trade openness index proposed by Squalli and Wilson (2011) according to the following relationship:

$$CTS = \frac{1}{x}(WTS_i * TS_i)$$

6

$$CTS = n\,(WTS_i * TS_i)$$

7

$$CTS = \frac{n(M+X)_i^2}{PIB\sum_{j=1}^{n}(M+X)_j}$$

8

Or:

$$CTS = \frac{(M+X)_i}{\frac{1}{n}\sum_{j=1}^{n}(M+X)_j}\,\frac{(M+X)_i}{PIB_i}$$

9

Intuitively, CTS (Composite Trade Share) represents TS adjusted by the proportion of a country's level of trade relative to the average world trade. Indeed, Udeagha and Ngepah (2022b) recently used CTS in their analysis of the relationship between fiscal decentralization and environmental degradation. They thus catch up with similar works of Ho and Iyke (2019); Mignamissi and Nguekeng (2022) and Gandjon Fankem and Feyom, (2023).

3.4. Empirical strategy

We apply several empirical estimation techniques to estimate the relationship described in Eq. (3). We start by the OLS estimator, then the Generalized Least Squares (GLS) method and the instrumental variables estimator. The GLS fit the linear panel data models using the feasible generalized least squares, under the hypothesis of the existence of heteroscedasticity, that is confirmed by the Breusch-Pagan test of Koenker (1981) in the appendix (table A2). For robustness of standard errors to a general forms of cross-sectional and time dependencies, we use the nonparametric technique of Driscoll Kraay (1998), which is robust when the error structure is heteroscedastic (Adams and Kaffo, 2022). Finally, due to the fact it could exist a problem of endogeneity in the relationship between trade openness and environmental quality (Grossman and Krueger, 1995; Frankel and Rose, 2005), we apply the instrumental variables (IV) methods to address this issue. Namely, we employ the Two Stage Least Square (2SLS) estimator and the estimator of the Generalized moments method (GMM). The 2SLS (with internal and external instrumentation) are used as the main estimation technique while the GMM estimator is reserved for robustness check. The internal instrumentation by the 2SLS estimator is carried out through the lag of the endogenous regressor (trade openness). With regard to the external instrumentation, some authors recommend to use the size (area) of countries as an external instrument of trade openness (see Frankel and Rose, 2005; Gantman and Dabós, 2017; Mignamissi and Nguekeng, 2022; Gandjon Fankem and Feyom, 2023). Yet, the 2SLS technique usually rise the question of model identification, and three main tests are typically used. The first is the classification test, which is an under-identification test developed by Kleibergen and Paap (2006). This test allows to determine whether the correlation between the endogenous variables and the instruments is statistically different from zero (i.e. $Corr[X, I_1]$and $Corr[X, I_2]$is statistically different from zero). The second test, developed by Stock and Yogo (2005), characterizes the weakness of the selected instruments, for which a multivariate specification was developed by Cragg and Donald (1993). Third, Hansen (1982) and Sargan (1983) also proposed a test for over-identification of all instruments, commonly known as the instrument validity test. Like the previous tests, it validates the relevance of the selected instruments.

4. Results and discussion

In turn, we present and discuss the baseline results, the sensitivity analysis and the robustness checks.

4.1. Baseline results

Table 1 presents the results of the OLS estimation of the effect of trade openness on CO2 emissions. The results reported show that trade openness has a positive and statistically significant effect on CO2 emissions regardless of the chosen specification. Column 1 presents the results of the bivariate model, where we can see that the coefficient associated with the variable of interest suggest that an increase of 1% in the level of trade openness following (CTS) leads to an increase of 0.0753% of CO2 emissions. Thus, the intensification of trade between African countries and the rest of the world leads to an increase in environmental degradation. This is due to the fact that African countries face lax environmental regulations and thus benefit from the externalities of polluting companies from the rest of the world: this is *environmental dumping*, which finds its explanation in the *pollution haven hypothesis* (Copeland and Taylor, 2004; Antweiler and al., 2001). In column 2, we control with GDP per capita. We note that the coefficient associated with the trade openness (CTS) of Squalli and Wilson (2011) remains positive and statistically significant at the 1% level. This tends to confirm the pollution haven hypothesis of which the African countries are victims (Adams and Opoku, 2020; Nurgazina et al., 2021; Pata and Caglar, 2021; Adams and Kaffo, 2022). The result reflects the fact that an increase in economic growth leads to an intensification of CO2 emissions (Khan and al, 2020). In columns (3)–(5), adding control variables such as financial development, industrial and agricultural activities lead to an increase of environmental degradation, while column (6) shows a negative effect of population on CO2 emissions. Our results are different to those of Singhania and Saini (2021) and Sarkodie and Adams (2018).

Table 1
Trade openness and CO2 emissions (OLS estimate)

	(1)	(2)	(3)	(4)	(5)	(6)
	OLS estimate					
VARIABLES	Dependent variable: CO2 per capita					
CTS	0.0753***	0.0299***	0.0302***	0.0286***	0.0269***	0.0496***
	(0.00651)	(0.00725)	(0.00604)	(0.00659)	(0.00676)	(0.00731)
lnGDP per capita		1.201***	1.171***	1.110***	1.194***	1.010***
		(0.0616)	(0.0730)	(0.0747)	(0.0819)	(0.0845)
Financial development			0.00845***	0.0105***	0.0117***	0.00895***
			(0.00281)	(0.00285)	(0.00293)	(0.00288)
Industrialization				0.0120*	0.0172**	0.0224***
				(0.00624)	(0.00686)	(0.00752)
Agriculture					0.00885***	0.0112***
					(0.00228)	(0.00243)
lnPopulation						-0.238***
						(0.0259)
Constant	0.568***	-7.691***	-7.586***	-7.354***	-8.223***	-3.319***
	(0.0495)	(0.401)	(0.458)	(0.476)	(0.579)	(0.838)
Observations	1,123	1,068	942	836	836	836
R-squared	0.261	0.641	0.680	0.697	0.699	0.720
Note: *, **, *** denote statistical significance at the 10%, 5% and 1% levels respectively. Robust standard errors reported in parenthesis.						

Source

authors.

Although the OLS method provides results that show the positive effect of trade openness on CO2 emissions, these results however suffer from some problems, in which the most important after the problems of endogeneity are the problems of autocorrelation and heteroscedasticity. To solve these issues, we apply under condition of validation of the test of Breusch Pagan, the GLS and the OLS Driscoll-Kraay estimator. The results obtained using these methods are shown in Tables 2. They largely confirm the OLS results.

Table 2

Trade openness and CO2 emissions (General least square and Driscoll Kraay)

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	GLS estimation				Driscoll kraay			
VARIABLES	Dependent variable: CO2 per capita							
CTS	0.0710***	0.0390***			0.0753***	0.0496***		
	(0.00269)	(0.00414)			(0.00732)	(0.00684)		
WTS			3.925***	2.882***			4.395***	3.148***
			(0.205)	(0.241)			(0.218)	(0.306)
lnGDP per capita		0.660***		0.631***		1.010***		0.969***
		(0.0310)		(0.0306)		(0.0971)		(0.0861)
Financial development		0.00687***		0.00860***		0.00895***		0.00856***
		(0.00116)		(0.00118)		(0.00140)		(0.00131)
Industrialization		0.00854***		0.00919***		0.0224**		0.0261***
		(0.00264)		(0.00267)		(0.00928)		(0.00884)
Agriculture		0.00234*		0.00260**		0.0112**		0.0101**
		(0.00130)		(0.00132)		(0.00430)		(0.00390)
lnPopulation		-0.222***		-0.281***		-0.238***		-0.304***
		(0.0140)		(0.0151)		(0.0207)		(0.0229)
Constant	0.372***	-0.806**	0.387***	0.285	0.568***	-3.319***	0.593***	-2.005***
	(0.0126)	(0.346)	(0.0130)	(0.369)	(0.0295)	(0.689)	(0.0223)	(0.640)
Observations	1,123	836	1,123	836	1,123	836	1,123	836
R-squared					0.261	0.720	0.260	0.738
Number of groups					41	41	41	41
Note: *, **, *** denote statistical significance at the 10%, 5% and 1% levels respectively. Robust standard errors reported in parenthesis.								

Source

authors.

We therefor apply the 2SLS estimation to solve the endogeneity problem and report the results in Table 3. The lower part of Table 3 reports that the various tests applied validate the specification of the model. We note that whatever the 2SLS specification (external instrumentation or internal instrumentation), CTS and WTS present a positive and significant effect suggesting that and improvement in trade openness either measured by CTS or by WTS, leads to an intensification of CO2 emissions. This result is consistent with those obtained in Table 2.

Table 3

Trade openness and CO2 emissions (2SLS)

	(1)	(2)	(3)	(4)
	2SLS			
	External instrumentation		Internal instrumentation	
VARIABLES	Dependent variable: CO2 per capita			
CTS	0.107**		0.0571***	
	(0.0422)		(0.00812)	
WTS		4.505***		3.015***
		(1.473)		(0.403)
lnGDP per capita	0.915***	0.972***	1.151***	1.125***
	(0.217)	(0.183)	(0.0898)	(0.0886)
Financial development	-0.00274	0.00333	0.00770***	0.00898***
	(0.00879)	(0.00486)	(0.00274)	(0.00278)
Industrialization	0.0400***	0.0349***	0.0475***	0.0434***
	(0.0114)	(0.0104)	(0.00931)	(0.00877)
Agriculture	0.0205***	0.0188***	0.0260***	0.0237***
	(0.00485)	(0.00493)	(0.00329)	(0.00326)
lnPopulation	-0.357**	-0.350***	-0.206***	-0.248***
	(0.140)	(0.118)	(0.0327)	(0.0328)
Regional dummies	Yes	Yes	Yes	Yes
Constant	-1.487	-1.909	-5.716***	-4.787***
	(3.753)	(3.218)	(1.048)	(1.061)
Observations	785	785	733	733
R-squared	0.723	0.750	0.755	0.761
S-Y 10% maximal IV size	19.93	19.93	19.93	19.93
S-Y 15% maximal IV size	11.59	11.59	11.59	11.59
S-Y 20% maximal IV size	8.75	8.75	8.75	8.75
Hansen p-value	0.674	0.650	0.270	0.186
KP-LM test p-value	0.000	0.000	0.000	0.000
F-stat	14.75	28.02	97.14	129.8
Note: *, **, *** denote statistical significance at the 10%, 5% and 1% levels respectively. Robust standard errors reported in parenthesis.				

Source

authors.

4.2. Sensitivity analysis

Based on the idea that some unaccounted factors could affect the previously obtained results, we perform several sensitivity tests in this subsection. We firstly start by assessing the effects of alternative measures of trade openness on CO2 emissions in African countries. Second, we proceed to include in the initial specification, additional variables (natural resources rent, cultural and historical variables). Finally, we control for heterogeneity related to sub-regional specificities in Africa using the World Bank classification.

4.2.1. Alternative measures of trade openness

Following Gräbner et al. (2021), we use six alternative indicators of trade openness, namely: four de facto trade openness indicators ((i) Exports share (Export); (ii) imports share (Import); (iii) Trade share (TS); (iv) Globalized Index of de facto of trade openness measures (KOFTrGIdf). To these de facto openness indicators, we add (v) the global trade openness index (KOFTrGI) and (vi) its de jure sub-dimension (KOFTrGIdj). The results reported in Table 4 remain consistent with the bassline results. Imports, Exports and trade share are positively and significantly associated to CO2 emissions in Africa. Although sometimes mixed, the results remain consistent according to the other measures of trade openness.

4.2.2. Sensitivity to natural resources, historical and cultural variables

4.2.2.1. Environmental curse: the role of natural resources

The large-scale exploitation of natural resources in countries that are highly endowed with them could contribute to weakening the environmental balance (Ulucak and Ozcan, 2020). In other words, the level of pollution would be an increasing function of the exploitation of natural resources and therefore of their rents. Using data from the World Bank Development Indicators, the results obtained show that natural resources rent is positively associated with environmental pollution, attesting to the idea of an environmental curse (Wang et al., 2020; Alfalih and Hadj, 2022). Compared to the global effect of all resources rent, natural gas and oil rents seem more polluting. Furthermore, taking natural resources into account does not change the previously established relationship between trade openness and environmental pollution through CO2 emissions (see Table 5).

4.2.2.2. Sensitivity of results to cultural and historical variables.

Table 6 provides evidences that cultural and historical factors significantly explain environmental outcomes in Africa. More specifically, our results are in agreement with the literature and show that the language spoken, the level of ethnic fractionalization and religion significantly reduce CO2 emissions in Africa. Similar results are found in the work of Álvarez-Díaz et al. (2011) who showed from a global sample that ethnolinguistic fractionalization reduces CO2 emissions. Furthermore, similar to Koehrsen (2015), we find that a strong presence of religiosity contributes to reducing CO2 emissions in that religious groups often form circles of pro-environment supporters, then promote clean energy adoption. Álvarez-Díaz et al. (2011) also showed that the Protestant religion strongly contributes to improving the quality of the environment.

4.2.3. Regional heterogeneity

Although the relationship between trade openness and CO2 emissions is positive in the overall sample of African countries, there may be asymmetric differences in sign or magnitude between the main sub-regions of the continent. Following the World Bank partition, we retain five main African sub-regions, namely East Africa, Central Africa, North Africa, Southern Africa and East Africa. The results obtained in Table 7 reveal that there are two types of asymmetry. The first, linked to the sign of causality, show that trade openness significantly reduce CO2 emissions in Central and East African countries. In contrast, trade openness significantly increases CO2 emissions in North, Southern and Western Africa. The second asymmetry is related to the difference on elasticities. For example, the positive effect of trade openness is

Table 4
Alternative measure of Trade openness

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
	2SLS									
	external instrumentation						Internal instrumentation			
VARIABLES	Dependent variable : CO2 per capita									
Trade Share	0.0331**						0.00676***			
	(0.0129)						(0.00134)			
Import		0.0549**						0.00618***		
		(0.0222)						(0.00214)		
Export			0.0825**						0.00982***	
			(0.0339)						(0.00375)	
KOFTrGI				-0.0701**						0.0130**
				(0.0287)						(0.00641)
KOFTrGIdf					-0.0356***					
					(0.0135)					
KOFTrGIdj						0.0237**				
						(0.0113)				
lnGDP per capita	1.087***	1.467***	0.519	1.460***	1.332***	0.272	1,280***	1.390***	1.023***	1.313***
	(0.124)	(0.137)	(0.322)	(0.109)	(0.0830)	(0.189)	(0.244)	(0.260)	(0.0675)	(0.0629)
financial development	0.0248***	0.0208***	0.0308***	0.0333***	0.0253***	0.00569	0.00306	0.00252	0.0261***	0.0180***
	(0.00360)	(0.00319)	(0.00485)	(0.00714)	(0.00426)	(0.00403)	(0.00270)	(0.00260)	(0.00381)	(0.00345)
Industrialization	0.101***	0.0953***	0.109***	0.0310***	0.0256***	-0.0402***	-0.0481***	-0.0481***	0.0379***	0.0538***
	(0.0199)	(0.0186)	(0.0244)	(0.00725)	(0.00777)	(0.00460)	(0.00544)	(0.00564)	(0.00499)	(0.00823)
Agriculture	0.0535***	0.0528***	0.0544***	0.00250	0.0108***	0.00103	-0.0125***	-0.0111***	0.0139***	0.0309***
	(0.0141)	(0.0144)	(0.0150)	(0.00570)	(0.00302)	(0.00407)	(0.00383)	(0.00349)	(0.00234)	(0.00319)
lnPopulation	0.333*	0.370*	0.274*	-0.252***	-0.244***	-0.593***	-1.261***	-1.267***	-0.0955***	0.0113
	(0.183)	(0.205)	(0.165)	(0.0726)	(0.0622)	(0.0940)	(0.193)	(0.196)	(0.0333)	(0.0288)
Constant	-17.35***	-20.32***	-12.81***	-3.499*	-3.859**	11.52***	16.04***	15.48***	-6.349***	-10.93***
	(3.969)	(5.298)	(2.432)	(1.958)	(1.628)	(1.291)	(1.884)	(1.797)	(0.656)	(0.856)
Country dummies	No	No	No	No	No	Yes	Yes	Yes	No	No
times dummies	No	No	No	No	No	No	No	No	No	No
regional dummies	Yes	Yes	Yes	No	No	No	No	No	No	Yes
Comments	706	706	706	836	836	786	702	702	559	733
R-squared	0.491	0.472	0.408	0.522	0.630	0.978	0.970	0.969	0.749	0.729
SY 10% maximum IV size	19.93	19.93	19.93	19.93	19.93	19.93	19.93	19.93	19.93	19.93
SY 15% maximum IV size	11.59	11.59	11.59	11.59	11.59	11.59	11.59	11.59	11.59	11.59
SY 20% maximum IV size	8.75	8.75	8.75	8.75	8.75	8.75	8.75	8.75	8.75	8.75

Note: *, **, *** denote statistical significance at the 10%, 5% and 1% levels respectively. Robust standard errors reported in parenthesis.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Hansen p-value	0.273	0.215	0.432	0.304	0.931	0.444	0.122	0.369	0.554	0.489
KP-LM p-value test	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
F-stat	19.39	17.05	13.42	23.32	39.57	16.12	47.40	83.63	168.1	215.5
Note: *, **, *** denote statistical significance at the 10%, 5% and 1% levels respectively. Robust standard errors reported in parenthesis.										

Source

authors.

Table 5

Sensitivity of results to natural resources

	(1)	(2)	(3)	(4)	(5)
	2SLS				
VARIABLES	Dependent variable : CO2 per capita				
CTS	0.0547***	0.0475***	0.0479***	0.0456***	0.0402***
	(0.00797)	(0.00870)	(0.00868)	(0.00873)	(0.00867)
Forest rents	**0.0485*****	**0.0444*****	**0.0442*****	**0.0425*****	**-0.184****
	(0.00760)	**(0.00721)**	**(0.00722)**	**(0.00670)**	**(0.0794)**
Oil rents		**0.0666*****	**0.0659*****	**0.0560*****	**-0.171****
		(0.0140)	**(0.0142)**	**(0.0142)**	**(0.0803)**
Mineral rents			**0.0134**	**0.0135**	**-0.246*****
			(0.00856)	**(0.00863)**	**(0.0893)**
Natural Gas rents				**0.316*****	**0.0400**
				(0.0781)	**(0.123)**
Total Natural resource rents					**0.228*****
					(0.0801)
Control variables	Yes	Yes	Yes	Yes	Yes
regional dummies	Yes	Yes	Yes	Yes	Yes
Constant	-6.887***	-3.270***	-3.416***	-2.835***	-2.946***
	(1.096)	(0.869)	(0.889)	(0.858)	(0.834)
Comments	733	733	733	733	733
R-squared	0.765	0.796	0.796	0.808	0.813
SY 10% maximum IV size	19.93	19.93	19.93	19.93	19.93
SY 15% maximum IV size	11.59	11.59	11.59	11.59	11.59
SY 20% maximum IV size	8.75	8.75	8.75	8.75	8.75
Hansen p-value	0.320	0.153	0.147	0.126	0.115
KP-LM p-value test	0.000	0.000	0.000	0.000	0.000
F-Stat	96.62	101.2	100.5	101.4	101.9
Note: *, **, *** denote statistical significance at the 10%, 5% and 1% levels respectively. Robust standard errors reported in parenthesis.					
Source: authors					

Table 6
Analysis of sensitivity to cultural and historical variables

	(1)	(2)	(3)
	2SLS		
VARIABLES	CO2		
CTS	0.123***	0.217***	0.103*
	(0.0420)	(0.0749)	(0.0552)
lnGDP per capita	0.875***	0.207	0.796***
	(0.215)	(0.365)	(0.297)
financial development	-0.00530	-0.0172	0.00350
	(0.00909)	(0.0158)	(0.0106)
Industrialization	0.0405***	0.0215	0.0364***
	(0.0121)	(0.0152)	(0.0115)
Agriculture	0.0220***	0.00675	0.0221***
	(0.00498)	(0.00740)	(0.00680)
lnPopulation	-0.355**	-0.672***	-0.240
	(0.144)	(0.254)	(0.195)
language	**-0.608*** **	**-0.234**	**0.285**
	(0.209)	**(0.198)**	**(0.223)**
Ethnic		**-2.338*** **	**-1.786*** **
		(0.537)	**(0.388)**
Religion			**-1.349*** **
			(0.284)
regional dummies	Yes	Yes	Yes
Constant	-0.863	10.72	-0.816
	(3.760)	(6.776)	(5.340)
Comments	760	741	741
R-squared	0.700	0.536	0.771
SY 10% maximum IV size	19.93	19.93	19.93
SY 15% maximum IV size	11.59	11.59	11.59
SY 20% maximum IV size	8.75	8.75	8.75
Hansen p-value	0.712	0.330	0.799
KP-LM p-value test	0.000	0.00635	0.00467
F-stat test	15.01	10.12	10.73

Note: *, **, *** denote statistical significance at the 10%, 5% and 1% levels respectively. Robust standard errors reported in parenthesis.

Source

authors.

more important in Southern Africa, thus reflecting the intensives economic activities of those countries. These results allow us to consolidate the two relevant fundamental hypotheses identified in the literature, namely the pollution haven hypothesis (North, Southern and Western Africa) and the pollution halo hypothesis (Central and Eastern Africa).

Table 7
Accessing the heterogeneity of the relationship

	(1)	(2)	(3)	(4)	(5)
	OLS estimate				
	Eastern Africa	Middle Africa	Northern Africa	Southern Africa	Western Africa
VARIABLES	Dependent variable : CO2 per capita				
CTS	-0.0316***	-0.121**	0.00852***	0.0535***	0.00401*
	(0.0114)	(0.0554)	(0.00204)	(0.00631)	(0.00229)
Control variables	Yes	Yes	Yes	Yes	Yes
Country dummies	Yes	No	No	No	No
Constant	28.82***	-12.65***	-18.08***	-22.25***	-1.333***
	(6.199)	(2.306)	(1.986)	(2.284)	(0.341)
Comments	258	112	54	80	281
R-squared	0.978	0.864	0.922	0.991	0.671
Note: *, **, *** denote statistical significance at the 10%, 5% and 1% levels respectively. Robust standard errors reported in parenthesis.					

Source

authors.

5. Robustness checks

We perform three main robustness analysis to access the solidity of the previous obtained results. First we use others indicators of environmental quality. Second, we examine the effect of trade openness on different points of the conditional distribution of CO2 emissions with regard to its dispersion using a quantile regression approach. Next, we control for endogeneity in this conditional distribution using the instrumental variable quantile regression method (IVQREG2). In addition, we control the robustness of this quantiles instrumental variable through an alternative specification, notably the smoothed instrumental variable quantile regression (SIVQR) introduced by Kaplan and Sun (2017). Third, we conclude with an application of the system GMM which is more robust than the 2SLS estimator in the presence of heteroscedasticity.

5.1. Other indicators of environmental quality

Environmental pollution is a multidimensional phenomenon, usually measured through several indicators that are sometimes complementary. The objective of this analysis is to assess whether the effect of trade openness is the same while considering different air polluting indicators. For this purpose, we retain three environmental pollution indicators, namely the nitrous oxide (N2O) emissions, greenhouse gases (GHG) emissions (that is the aggregate measure of several polluting gases), and the fine particles (PM2.5) emission (which is an air quality indicator that identifies the fine particles present in the air, with a diameter measuring no more than 2.5 micrometers (μm). It usually refers to a mixture of smoke, soot, aerosols or biological materials such as fungi or bacteria. The results in Table 8 confirm the harmful nature of trade openness on these different indicators of environmental pollution. However, the effect is greater on greenhouse gases, due to its multi-dimensional component.

Table 8
Others indicators of environmental quality

	(1)	(2)	(3)
	2SLS		
VARIABLES	N2O	PM2.5	GES
CTS	0.00683**	0.0244*	0.0411***
	(0.00328)	(0.0140)	(0.00680)
lnGDP per capita	-0.0108	-0.0524	0.00861
	(0.0131)	(0.0745)	(0.0476)
Financial development	-0.00145**	-1.002***	0.0686
	(0.000703)	(0.333)	(0.242)
Industrialization	-0.000156	0.00527	-0.0106*
	(0.000806)	(0.00612)	(0.00571)
Agriculture	-0.000360	0.00371	-0.00262
	(0.000250)	(0.00298)	(0.00176)
lnPopulation	0.0331***	-0.0479	0.0277
	(0.0116)	(0.0530)	(0.0293)
Regional dummies	Yes	No	Yes
Constant	-0.400	1.500	-0.340
	(0.274)	(1.348)	(0.757)
Observations	785	389	568
R-squared	0.410	0.107	0.449
S-Y 10% maximal IV size	19.93	19.93	19.93
S-Y 15% maximal IV size	11.59	11.59	11.59
S-Y 20% maximal IV size	8.75	8.75	8.75
Hansen p-value	0.909	0.684	0.114
KP-LM test p-value	0.000	0.000	0.000
F-stat	16.21	22.23	80.63
Note: *, **, *** denote statistical significance at the 10%, 5% and 1% levels respectively. Robust standard errors reported in parenthesis.			

Source

authors.

5.2. Effect of trade openness on CO2 emissions: a non-parametric approach

5.2.1. A quantile regression approach

Given that the OLS estimator only focuses on the average effect and does not take into account the effect that the trade openness (CTS) might have on different level of CO2 emissions, we use the quantile regression (QR) approach introduced by Koenker and Bassett (1978). The QR has the particularity of taking into account the effect of a given variable on another at different points of its distribution. This approach is more robust than the OLS approach for several reasons. For example, it is appropriate when the errors are not normally distributed (in Table A2, the Shapiro and Wilk test confirms the intuition that the variables are not normally distributed), and when it may exist some outliers. Furthermore, when the distribution of the dependent variable is large, we could observe a high variability of the mean in the presence of strong heterogeneity in the sample (Cade and Noon, 2003). Thus, QR provides a more precise description of the distribution of a conditional variable of interest on its determinants than a simple linear regression that focuses on the conditional mean. Following the work of Binder and Coad (2011), the quantile regression model can be written as follows:

$$y_{it} = x'_{it}\beta_\theta + u_{\theta it} \text{with} Quant_\theta\left(y_{it}|x_{it}\right) = x'_{it}\beta_\theta$$

Where $y_{it}$is the volume of CO2 emissions, $\beta$is the vector of parameters to be estimated, $x_{it}$is a vector of regressors and u is the vector of residuals. $Quant_\theta\left(y_{it}|x_{it}\right)$represents the θth conditional quantile of $y_{it}$for a given x_{it}. The quantile estimator is obtained by solving the following optimization problem for the θth quantile (0 < θ < 1):

$$\min_{\beta \in R^K} \left[\sum_{i,t:y_{it} \geq x_{it}'\beta} \theta |y_{it} - x_{it}'\beta| + \sum_{i,t:y_{it} \geq x_{it}'\beta} (1-\theta) |y_{it} - x_{it}'\beta| \right]$$

The results obtained by the quantiles regression estimation are presented in Table 9. Columns (2) to (6) present the estimates for the 10th, 25th, 50th, 75th and 95th quintiles. We observe that the positive effect of trade openness according to the indicator of Squalli and Wilson (2011) (CTS) varies considerably along the distribution of CO2 emissions. More precisely, the effect is statistically significant on all quantile distributions. The effect is more accentuated and significant at the 1% threshold for relatively high CO2 emission levels. These results are confirmed in Fig. 4 which illustrates how the positive effects on CO2 emissions vary across quantiles, and how the magnitude of the effects at different quantiles differ significantly from the OLS coefficient (horizontal line).

Table 9
Quantile regression estimation

	(1)	(2)	(3)	(4)	(5)	(6)
	OLS	Q10	Q25	Q50	Q75	Q90
VARIABLES	Dependent variable: CO2 per capita					
CTS	0.0496***	0.0126***	0.0141***	0.0411***	0.0865***	0.0618***
	(0.00731)	(0.00147)	(0.00256)	(0.00440)	(0.00673)	(0.0125)
lnGDP per capita	1.010***	0.341***	0.449***	0.475***	0.662***	1.100***
	(0.0845)	(0.0157)	(0.0274)	(0.0471)	(0.0721)	(0.134)
Financial development	0.00895***	0.0113***	0.0132***	0.00922***	0.00794***	0.00997**
	(0.00288)	(0.000585)	(0.00102)	(0.00175)	(0.00268)	(0.00500)
Industrialization	0.0224***	0.0156***	0.0228***	0.0168***	0.0337***	0.00292
	(0.00752)	(0.00172)	(0.00299)	(0.00514)	(0.00788)	(0.0147)
Agriculture	0.0112***	0.00450***	0.00684***	0.00313	0.00391	-0.00641
	(0.00243)	(0.000995)	(0.00174)	(0.00298)	(0.00457)	(0.00851)
lnPopulation	-0.238***	-0.0612***	-0.0838***	-0.257***	-0.316***	-0.147**
	(0.0259)	(0.00850)	(0.0148)	(0.0255)	(0.0390)	(0.0727)
Constant	-3.319***	-1.659***	-2.112***	0.857	0.612	-3.853**
	(0.838)	(0.213)	(0.372)	(0.639)	(0.978)	(1.823)
Observations	836	836	836	836	836	836
R-squared	0.720					
Pseudo R2		0.2636	0.3254	0.4247	0.5813	0.6306
Note: *, **, *** denote statistical significance at the 10%, 5% and 1% levels respectively. Robust standard errors reported in parenthesis.						

Source

authors.

5.2.2. Structural instrumentation: quantile function estimation

Due to the existence of a potential endogeneity bias in the specification of Eq. (3) and the scatter of our dependent variable, the instrumental variable quantile regression approach (IVQREG2) of Chernozhukov and Hansen (2008) is more robust than a simple estimation by quantile regression in controlling the initial and progressive levels of CO2 emissions (Chang et al., 2018; Mignamissi and Djeufack, 2022). The advantage of the instrumental variable quantile regression technique is to examine the impact of explanatory variables at different quantiles of the conditional distribution of the dependent variable while accounting for unobserved factors that may possibly impact the dependent variable and which are correlated with the explanatory variables (Harding and Lamarche, 2009). Thus, on the assumption that the variables are not normally distributed in a model, also arises as in the linear regression model, the questioning of the assumption of exogeneity in the conditional distributions models (Chernozhukov and Hansen, 2008). The bias linked to the rejection of the exogeneity hypothesis lead to the quantile instrumentation procedure developed by (Chernozhukov and Hansen, 2008), in particular by using the external instrument retained for the 2SLS. The particularity of this estimation technique comes from the fact that it estimates the structural quantile functions defined by (Chernozhukov and Hansen, 2008) using the method of Machado and Silva (2019). If any instrument is specified, it estimates the quantile regression by imposing the restriction that the quantiles do not cross. The results contained in Table 10 report a positive and significant effect respectively at the 1% and 5% threshold of trade openness on CO2 emissions throughout the instrumental distribution of the quantiles of the panel. However, the distribution of the results provides coefficients that are different from those of the ordinary quantile regression and 2SLS and which are however more convergent whatever the distribution of the percentile. Our results thus confirm the pollution haven hypothesis as in the work of Chen Jiang and Kitila (2021).

Table 10
Structural instrumentation, quantile fonction estimation

	(1)	(2)	(3)	(4)	(5)	(6)
	Structural instrumentation quantile fonction estimation					
	2SLS	IVQ10	IVQ25	IVQ50	IVQ75	IV90
VARIABLES	Dependent variable: CO2 per capita					
CTS	0.107**	0.0189***	0.0233***	0.0307***	0.0442***	0.0635**
	(0.0422)	(0.00732)	(0.00571)	(0.00668)	(0.0148)	(0.0286)
lnGDP per capita	0.915***	0.388***	0.462***	0.584***	0.809***	1.131***
	(0.217)	(0.0744)	(0.0689)	(0.0628)	(0.0650)	(0.0972)
Financial development	-0.00274	0.0109***	0.0107***	0.0104***	0.00978	0.00893
	(0.00879)	(0.00301)	(0.00186)	(0.00245)	(0.00703)	(0.0141)
Industrialization	0.0400***	0.0204***	0.0206***	0.0208***	0.0212***	0.0218
	(0.0114)	(0.00393)	(0.00370)	(0.00457)	(0.00820)	(0.0144)
Agriculture	0.0205***	0.00670***	0.00643***	0.00597***	0.00513	0.00392
	(0.00485)	(0.00118)	(0.00115)	(0.00173)	(0.00342)	(0.00610)
lnPopulation	-0.357**	-0.123***	-0.121***	-0.118***	-0.113***	-0.106
	(0.140)	(0.0151)	(0.0177)	(0.0253)	(0.0430)	(0.0704)
Constant	-1.487	-1.164**	-1.563***	-2.226***	-3.444***	-5.191***
	(3.753)	(0.535)	(0.519)	(0.583)	(0.894)	(1.494)
Observations	785	836	836	836	836	836
R-squared	0.723					
S-Y 10% maximal IV size	19.93					
S-Y 15% maximal IV size	11.59					
S-Y 20% maximal IV size	8.75					
Hansen p-value	0.674					
F-Stat	14.75					
KP-LM test p-value	0.000627					
converged		1	1	1	1	1
Q		0.00175	0.00175	0.00175	0.00175	0.00175

Note: *, **, *** denote statistical significance at the 10%, 5% and 1% levels respectively. Robust standard errors reported in parenthesis.

Source

authors.

6.2.3. Smoothed instrumental variables quantile regression

We apply the smoothed instrumental variable quantile regression (SIVQR) estimator which is an improved version of the instrumental quantile regression, and introduced by Kaplan and Sun (2017). The main advantage of the SIVQR compared to the IVQR of Chernozhukov and Hansen (2008) is that it allows a fast calculation with many endogenous coefficients, compared to the latter which allows only one endogenous term. In order to compare the results obtained using the IVQR, the results of the SIVQR are presented in Table 11. Based on these results, the effect of trade openness on CO2 emissions remains robust. The effect is greater at the middle quantiles (50th and 75th quantile).

Table 11
Smoothed instrumental variables quantile regression

	(1)	(2)	(3)	(4)	(5)
	Smoothed instrumental variables quantile regression				
	SIVQ10	SIVQ25	SIVQ50	SIVQ75	SIVQ90
VARIABLES			CO_2 per capita		
CTS	0.0137**	0.142***	0.171***	0.190***	0.114***
	(0.00545)	(0.0470)	(0.0470)	(0.0734)	(0.0427)
lnGDP per capita	0.354***	-0.149	0.269	0.604	1.560***
	(0.0500)	(0.0999)	(0.191)	(0.380)	(0.304)
Financial development	0.0113	-0.00606	-0.0161***	-0.0271	-0.0170
	(0.00759)	(0.00878)	(0.00437)	(0.0266)	(0.0160)
Industrialisation	0.0206***	-0.0111	0.0116	0.0247	0.0239
	(0.00263)	(0.00780)	(0.0200)	(0.0410)	(0.0299)
Agriculture	0.00599***	-0.00283	-0.000301	0.0115	0.0163**
	(0.00222)	(0.00250)	(0.00332)	(0.0143)	(0.00707)
lnPopulation	-0.0606**	-0.283***	-0.517***	-0.565**	-0.0826
	(0.0300)	(0.0645)	(0.142)	(0.269)	(0.165)
Regional dummies	Yes	No	Yes	Yes	Yes
Constant	-1.856***	5.565***	6.740*	5.827	-8.537*
	(0.692)	(1.572)	(3.694)	(6.629)	(4.382)
Observations	785	836	785	785	785
bwidth	0.0992	0.123	0.179	1.473	0.279
bwidth_req	0.0992	0.123	0.179	0.265	0.279
bwidth_max	0.175	0.249	1.085	0.565	0.478
Q	0.100	0.250	0.500	0.750	0.950

Note: *, **, *** denote statistical significance at the 10%, 5% and 1% levels respectively. Robust standard errors reported in parenthesis.

Source

authors.

5.3. Alternative approach of instrumentation: SYS-GMM estimation

According to Baum et al., 2003, two instrumentation approaches dominate in the econometric literature, namely the two stage least squares estimator (IV-2SLS) and the GMM estimator. However, due to the possible persistence (memory effect) of CO_2 emissions, a dynamic model should be used, which is more suitable to the use of the GMM technique. Given the possible unknown heteroscedasticity in the residual structure of the model (See Table A2), Baum and al, (2003) recommend to use the GMM estimator, introduced by Hansen (1982). The validation of a GMM is cumbersome, because it relies on the consistency of several post-estimation tests. The chosen instruments must be valid, i.e. orthogonal to the error term, but strongly correlated with the endogenous variables. It is therefore important to compute adequate tests for this purpose. Moreover, because of the dynamics induced by the first-order autocorrelation of the dependent variable, a particular test of autocorrelation of the residuals must be implemented. It refers here to the test of presence/absence of the second-order autocorrelation of Arellano and Bond (1991). Moreover, the necessary conditions for the robustness of the results of the GMM according to Roodman (2009a) are met since the sample includes 41 countries observed over the period 1995–2019. Finally, to ensure the asymptotic efficiency of the results (see Blundell and Bond, 1998), we prefer the two-step System-GMM estimator to the one-step estimator, with the option collapse used to reduce instrument proliferation (see Roodman, 2009b). The results of the system GMM specification are presented in Table 12. The previous results are maintained, thus validating the main hypothesis of the study: trade openness (CTS), as measured by the sum of trade share (TS) and the world trade share (WTS), is associate with an increase of the level of CO_2 emissions in Africa.

Table 12
Other approach of instrumentation: the SYS-GMM estimator

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	SYS-GMM							
VARIABLES	Dependent variable: CO2 per capita							
L.CO2	0.935***	0.929***	0.939***	0.936***	0.939***	0.840***	0.907***	0.979***
	(0.00203)	(0.00156)	(0.00274)	(0.00236)	(0.00253)	(0.0109)	(0.0226)	(0.00250)
CTS	0.513***							
	(0.0125)							
WTS		0.386***						
		(0.0162)						
Trade			0.0145**					
			(0.00611)					
Export				0.0387**				
				(0.0174)				
Import					0.0220***			
					(0.00724)			
KOFTrGI						0.445***		
						(0.139)		
KOFTrGIdf							0.476**	
							(0.183)	
KOFTrGIdj								0.0731***
								(0.0125)
Constant	-0.147***	-0.0442	-0.333***	-0.336***	-0.408***	3.352***	1.308	-0.343***
	(0.0268)	(0.0587)	(0.0637)	(0.0621)	(0.0532)	(0.828)	(1.470)	(0.0439)
Control variables	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	808	808	732	732	732	808	808	759
Number of groups	41	41	39	39	39	41	41	40
Instruments	37	37	30	30	34	34	29	26
AR (1)	0.0678	0.0681	0.0667	0.0665	0.0675	0.0672	0.0602	0.0339
AR (2)	0.210	0.205	0.211	0.211	0.212	0.203	0.214	0.283
Hansen p-value	0.671	0.606	0.521	0.538	0.231	0.556	0.961	0.728

Note: *, **, *** denote statistical significance at the 10%, 5% and 1% levels respectively. Robust standard errors reported in parenthesis.

6. Conclusion and political implications

In this study, we analyzed the effect of trade openness on CO2 emissions on a large sample of 41 African countries on the period 1995–2019. Using the composite index of trade openness whose calculation methodology was proposed by Squalli and Wilson (2011), we applied the 2SLS estimation after taking into account possible problems of heteroscedasticity and autocorrelation through the GLS and the Driscoll-Kraay specification. The results show that trade openness increases CO2 emissions, so that a 1% increase in the level of trade openness increases CO2 emissions by 0.107%. These results imply that trade openness, regardless of how it is measured, leads to environmental degradation in Africa in general, through CO2 emissions as well as other greenhouse gases such as N2O and PM2.5. These observations are consistent with the hypothesis that trade openness can lead to pollution in developing countries. These countries, which are also strongly represented in Africa, are nevertheless largely dependent on foreign trade, which undermines the idea of considering measures aimed at reducing the level of trade. Moreover, African governments have entered since 2019, in a strong dynamic, that of forming the African Continental Free Trade Area (AfCFTA) with the aim of expanding intra-African trade by removing tariff barriers on trade in goods, commodities and services across the continent. As it is true that the AfCFTA will contribute to increasing trade in the region, in support of the trade that once existed with the rest of the world, if strong environmental measures are not put in place, the degradation of the environment in the form carbon emissions is set to get worse.

Policymakers must therefore set up and enforce strict standards that take into account the environmental impact of trade, and then include green technologies and resources in production and transport processes as well as in the goods produced and traded. To this end, an improvement in the quality of the baskets of goods traded could be more productive than an increase in the volume of trade. In addition, we found, the analysis of the heterogeneity in the trade openness-CO2 emission relationship revealed that some African sub-regions register rather a negative effect, indicating that the opening of these economies, precisely those of Central and East Africa, can contribute to reducing CO2 emissions. This agrees with similar findings obtained by including cultural variables. This second observation highlights the existence within African economies of differences both in the processes adopted and in the degree of commitment to the global fight against climate change, which is at the heart of current international concerns and whose African populations are the most vulnerable.

Declarations

Credit author statement

Dieudonne Mignamissi: Conceptualization, Supervision, Methodology, Writing-Original draft. **Eric Possi Tebeng**: Methodology, Data Curation, Investigation, Software, Writing-Original draft. **Arnold Dilane Momou Tchinda:** Investigation, Validation, Visualization, Writing-Original draft.

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The authors declare that they are not aware of any conflict of interest, whether material or financial, in connection with this study.

Data Availability statement

The data used in this study will be made available on request.

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Footnotes

[4] This refers to the measure of openness commonly used in the literature which is equal to the sum of a country's imports and exports relative to its GDP.

Figures

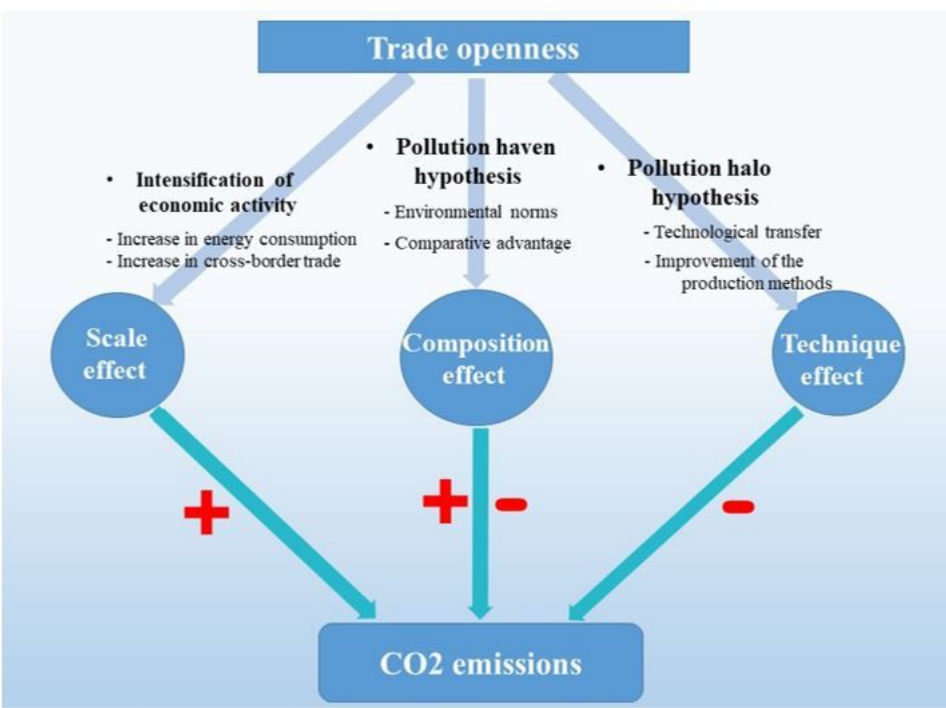

Figure 1

Theoretical framework

Source: author’s conception

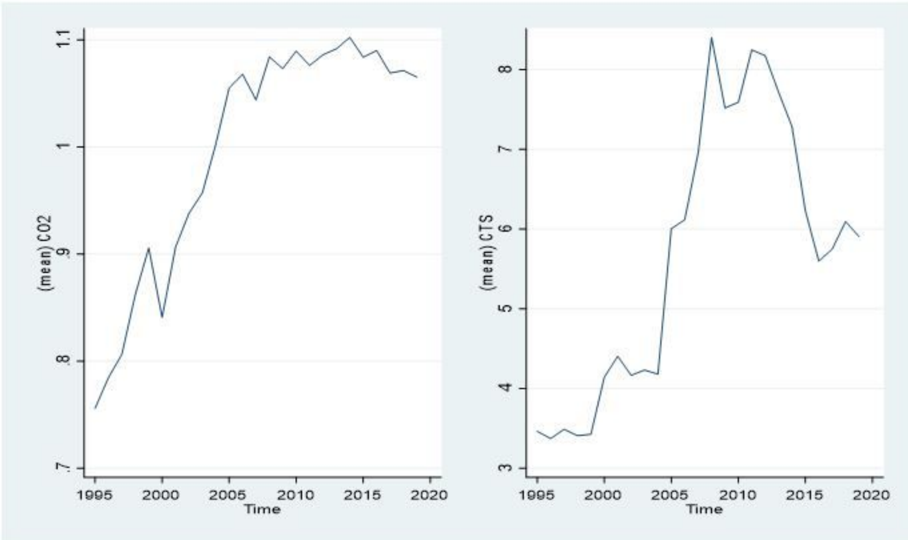

Figure 2

Comparative evolution of CO2 emissions and trade openness in Africa

Source: authors

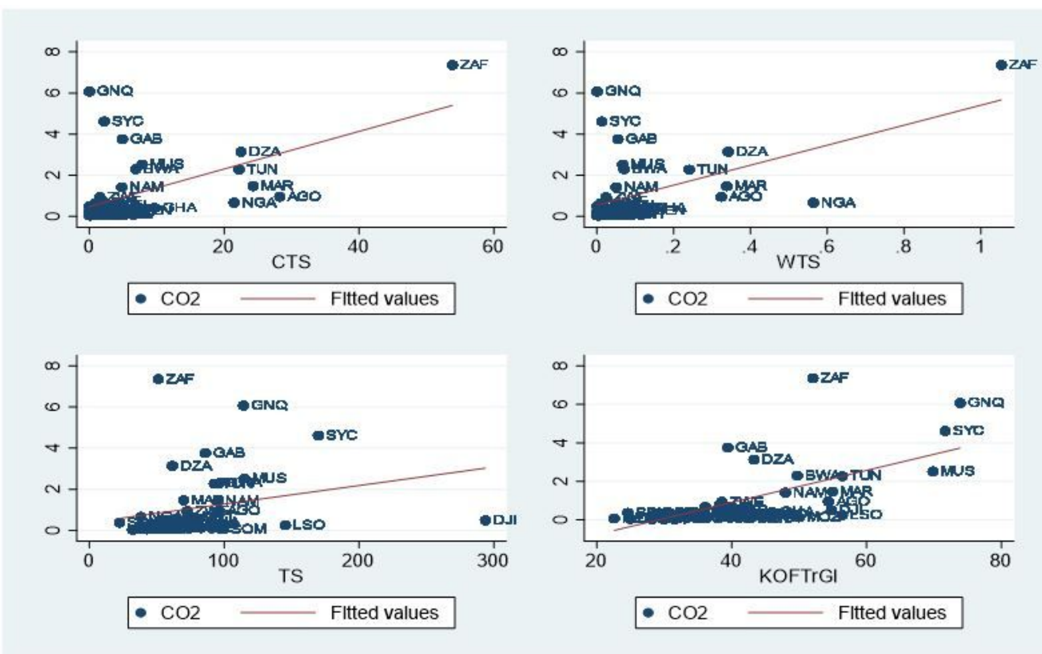

Figure 3

Correlation between trade openness measures and CO2 emissions in Africa

Source: authors

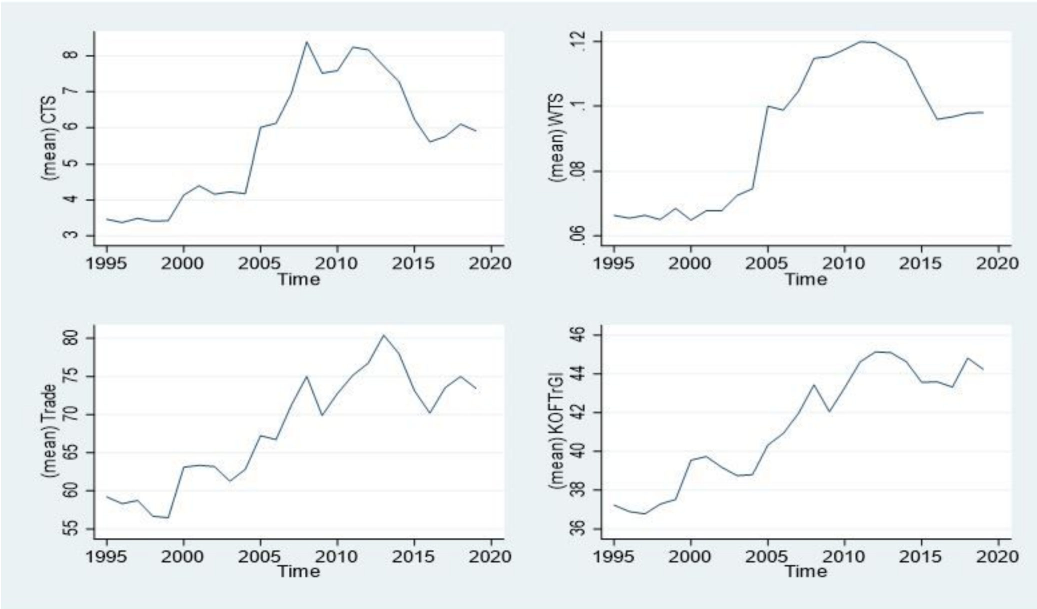

Figure 4

Comparative analysis of the evolution of trade openness according to its different measures in Africa

Source: authors

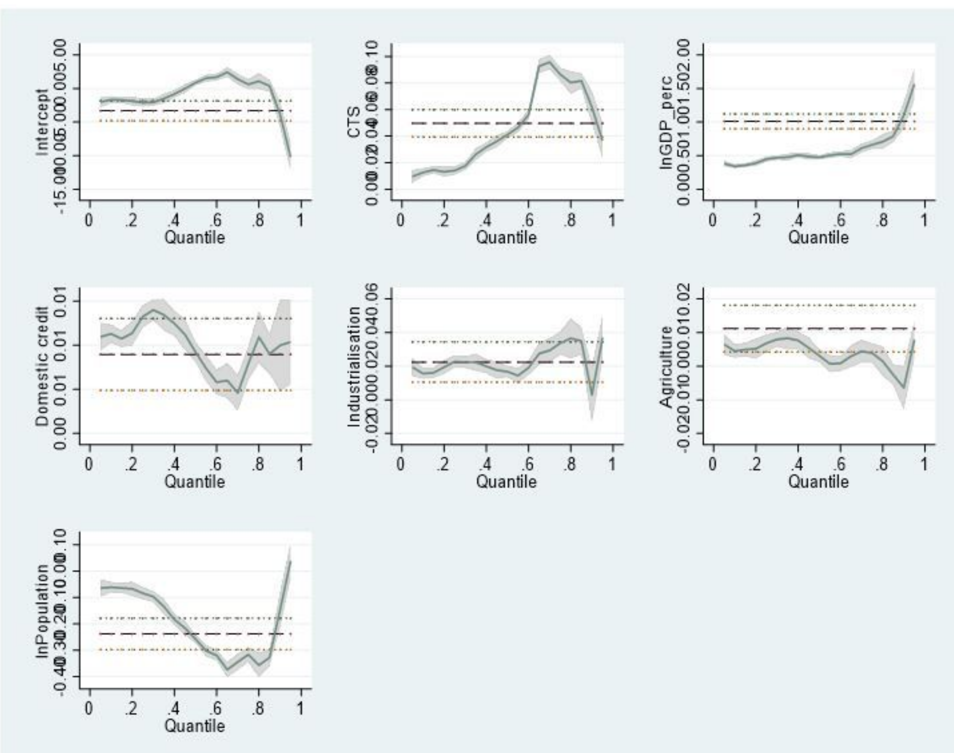

Figure 5

A graphical overview of the heterogeneity of the relationship

Source: authors

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