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Testing the role of oil production in the environmental Kuznets curve of oil producing countries: New insights from Method of Moments Quantile Regression

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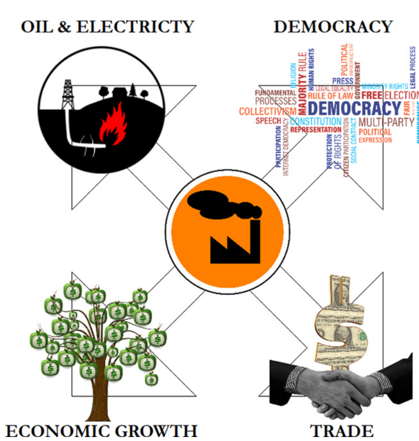
HIGHLIGHTS

- We examined the long-run effects of oil production on environmental pollution in oil-producing countries.
- We controlled for distributional heterogeneity using novel Method of Moments Quantile Regression.
- Oil and electricity production increases CO_2 emissions while trade decreases pollution.
- FMOLS, DOLS, and FE-OLS validated the EKC and Pollution Halo hypotheses.

GRAPHICAL ABSTRACT



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ABSTRACT

The global economic growth has triggered the continual increase in oil demand for transportation and petrochemical sectors which offshoots environmental pollution. Though there exists literature on environmental Kuznets curve, however, very few examine the scope in the light of fossil fuel energy production. This paper investigated the dynamic effect of oil production on carbon emissions in 15 oil-producing countries by accounting for the role of electricity production, economic growth, democracy, and trade over the period 1980–2010. Using the novel Method of Moments Quantile Regression (MMQR) with fixed effects, the results found an inverted U-shape relationship between economic growth and CO_2 emissions only at median and higher emission countries, thus, validating the environmental Kuznets curve hypothesis. Oil production increases CO_2 emissions significantly from the first to sixth quantiles with greater effect at the lowest quantile and weaker effect at the highest quantile. Electricity production was found to increase CO_2 emissions while trade condenses CO_2 emissions across all the quantiles thereby confirming the pollution halo hypothesis for oil-producing countries. The effect of democracy was positive across all the quantiles but only significant in countries with average CO_2 emissions. The findings provide insight for policymakers to mitigate CO_2 emissions in oil-producing countries through diversification and clean energy technologies such as carbon capture and storage.

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1. Introduction

One of the topmost issues of concern to government and policymakers in the 21st century is centred on environmental degradation associated with climate change. This issue arises mainly from the overdependence on fossil fuels (oil, gas, and coal) as the main source of energy to power economic growth (Bhattacharya et al. 2016; Rafindadi, 2016; Sarkodie, 2018; Sarkodie and Strezov, 2018; Rafindadi and Usman, 2019). The Intergovernmental Panel on Climate Change (IPCC) (2013) documents that about 76.6% of the emissions of carbon dioxide (CO_2) in the world is traceable to the various efforts to accelerate the pace of economic growth and raise the standard of living particularly in the developing countries, which has increased the demand for electricity substantially. According to Enerdata (2019), the world electricity production grew by 2.8% in 2017 and 1.9% in 2018 with a greater part of the growth coming from the oil-producing countries where the sources of energy are predominantly from fossil fuels. Similarly, out of the 49 Gt emissions of CO_2 equivalent in 2010, the contribution of electricity and heat production amounts to about 25%. This is closely followed by agricultural, forestry and land use with 24% while industrialization, transportation, other energy, and buildings are 21%, 14%, 9.6% and 6.4% (See IPCC, 2016). In addition, Katircioglu (2017) demonstrates that crude oil accounts for about 35% of world demand for energy and fossil fuels as a whole account for over 80% of the world demand for energy in 2004. This comes with tremendous economic benefits for oil-producing countries. As such, the incentive to phase out fossil fuel may entail serious short-term cost implications for these set of countries. In light of all the aforementioned developments, the objective of this study is to determine the heterogeneous impact of oil production on CO_2 emissions by controlling for the effects of electricity production, economic growth, democracy, and trade over the period 1980–2010. Due to the heterogeneous developmental stages of the countries within the panel, a novel Method of Moments Quantile Regression (MMQR) with fixed effects developed by Machado and Silva, (2019) is employed to control for distributional heterogeneity. This would uncover the latent effects of the exogenous variables across the conditional distribution of CO_2 emissions.

Several researchers have examined the effect of economic growth on environmental degradation. Most studies provide a positive relationship between economic growth and environmental degradation (See Shahbaz et al. 2013; 2017; Sarkodie and Strezov, 2018; Bekun et al. 2019; Usman et al. 2019a,b; Rafindadi and Usman, 2019). These results are theoretically underpinned by the pioneering work of Grossman and Krueger (1991), which categorically states that as a country progresses in the path of development, environmental degradation would initially increase as income per capita increases, but reduces subsequently as income per capita continues to increase above a certain threshold. This process leads to what is known as the Environmental Kuznets Curve hypothesis in the environmental economics literature. This hypothesis has been validated by several empirical studies over the years under three major channels, namely; the scale effect, composition effect, and technique effect. Regarding the scale effect, increasing the consumption of energy stimulates economic growth and hence increases environmental emissions (Cole, 2006; Dedeoglu and Kaya, 2013; Zaman & Moemen, 2017; Stern and Van Dijk, 2018; Sarkodie, 2018). Conversely, the composition effect, which is typically the case for industrial economies arise when a decrease in energy consumption stimulates economic activities due to a decline in the share of carbon-intensive goods in the production of goods and services (Stern, 2004; Farhani & Ozturk, 2015). The technique effect arises when a decrease in energy consumption, particularly fossil fuels — decreases CO_2 emissions due to the transmission of advanced technologies and technical know-how which improves energy efficiency and stimulates economic growth (Antweiler et al. 2001; Dollar and Kraay, 2004; Lorente and Alvarez-Herranz, 2016; Nassani et al. 2017).

In furtherance to the debates on the economic growth-environmental quality interactions, several studies have examined whether international trade contributes to environmental deterioration (Cole and Elliott 2003, Cole 2004; Nasir and Rehman 2011; Farhani et al. 2014; Ozturk and Acaravci 2016; Ozatac et al. 2017). Theoretically, international trade is expected to stimulate economic growth because it helps to re-allocate capital for investments from the capital abundant countries to labour abundant countries. As economic growth increases due to trade, the greenhouse gas (GHG) emissions resulting from the increase in energy consumption continues to threaten the quality of life and the environment (Cole and Elliott, 2003; Twerefou et al. 2019).

Recently, there is growing evidence that the democratic regime exerts pressure on environmental degradation (Farzin and Bond, 2006; Usman et al. 2019a). This strand of literature is built on a well-known theory of modernization accredited to Lipset (1959). This theory submits that a positive correlation exists between income and democracy. To this extent, democracy is expected to affect the level of environmental degradation through its effect on income. However, the direction to which democracy exerts pressure on CO_2 emissions can be either positive or negative. Some studies report that democracy improves environmental quality through adequate and effective implementation of government policies. Their argument is that as a country's level of democracy increases, peoples' freedom to express their preferences through protests tends to increase. This liberty in a democratic setting forces the government to pursue environmentally-friendly policies (Farzin and Bond, 2006; Payne, 1995; Torras & Boyce, 1998; Barrett & Graddy, 2000; and Shahbaz, et al. 2013; Usman et al. 2019a). On the other hand, some studies report that environmental quality is threatened in a democratic setting. This is because as income increases with the level of democracy, CO_2 emissions also tend to rise (see Heilbronner, 1974; Midlarsky, 1998; Scruggs, 1998; Roberts and Parks, 2007; Lv, 2017).

Even though the empirical research on the EKC has significantly increased over the years, the debate on the role of oil production, trade, and democracy in determining the position of the EKC for oil-producing countries remains unclear. The previous studies which apparently attempted to address this issue, (See Farzin and Bond, 2006; Lv, 2017; Usman et al. 2019a) failed to consider the case of oil-producing countries particularly in the developing countries where the challenge of high emissions of the GHGs remain a threat to the climate, due to less stringent environmental laws and pressing concerns for development. The causal effect of oil consumption on income and CO_2 emissions in MENA countries has also been validated by Al-Mulali (2011). However, the socio-economic dynamics of oil consumption are totally different from oil production. In effect, all countries are oil-consuming but not all countries are oil producers. Going further, more recent studies that analysed the effect of natural resources on CO_2 emissions in European countries (Balsalobre-Lorente et al, 2018, Bekun et al, 2019) utilized estimators of the traditional mean variants and came up with mixed results between them. Furthermore, the idiosyncrasies of oil-producing countries require that a separate empirical study on the income-pollution nexus be undertaken for these countries. Going by the Dutch disease and resource curse literature, oil-producing countries may be subject to a different set of economic realities in contrast to their non-oil producing counterparts. The resource curse literature is inundated with empirical evidence suggestive of a growth mitigating effect of resource dependence (Corden and Neary, 1982; Sachs and Warner, 1999). One often mentioned transmission mechanism is the downscaling of the industrial sector due to resource trade induced capital inflows, which undercuts the competition of other tradable commodities (Corden and Neary, 1982; Corden, 1984; Singer, 1950; Matsuyama, 1992). The present study would help to ascertain whether the growth mitigating effect of natural resources would have a similar effect on the emissions profile of oil-producing countries. Existing literature (Balsalobre-Lorente et al., 2018; Bekun et al., 2019) employed a more aggregate resource variable (natural resources) which gives no distinction between point sourced resources and diffuse ones as an exogenous variable. In contrast, this study employs a more specific natural resource (crude oil production) of the point sourced variant. Our choice of oil production in oil-producing economies stems from the fact that point sourced resources tend to have stronger negative growth effects than diffuse ones (Isham et al. 2005; Mehlum et al. 2006). Our sample cuts across both developed and developing oil-producing economies with an inclusion of institutional control variables like democracy in order to give more robust inferences because sound institutions have been seen to diminish the growth mitigating effect of resource dependence (Leite and Weidmann, 1999) or even reverse it. The 15 oil-producing countries captured in the present study include Algeria, Argentina, Brazil, Canada, China, Indonesia, Iran, Kuwait, Mexico, Nigeria, Norway, Saudi Arabia, United Kingdom, United States and Venezuela. The period of study spans from 1980 to 2010.[1] Therefore, because the selected countries are at different levels of economic development, our study investigates the validity of the income-induced CO_2 emissions nexus in the presence of oil production and other control variables across different quantiles of the conditional distribution of CO_2 emissions through the novel Method of Moments Quantile Regression of Machado and Silva (2019). This approach provides empirical insights into the distributional heterogeneity of this relationship by incorporating fixed effects. The method, therefore, allows for heterogeneous income-emissions nexus at different conditional quantiles distribution of the emissions, which might not be captured by the application of conventional mean regressions. Consequently, a comprehensive examination of the EKC hypothesis in oil-producing countries is explored. This paper, to the best of our knowledge, is the first to introduce distributional heterogeneity in investigating the income-induced CO_2 emissions in oil-producing countries by accounting for oil production, electricity production, democracy, and international trade. An assessment of the EKC hypothesis at different quantiles of the conditional distribution of emissions is necessary due to several reasons. First, unlike the estimates of the conditional mean which are prone to the distorting effects of outliers, the estimates of the conditional quantiles are more robust to outliers emanating from the dependent variable (Koenker 2004). Second, the conditional mean estimation fails to portray the full distributional impact of income on emissions. Quantile regression, on the other hand, has a more intuitive appeal especially in panel regressions as it stratifies the distributional effect of the independent variables on the dependent variable into different quantile ranges. Thus, it becomes easier to classify the heterogeneous effects of heterogeneous cross-sectional groups. Consequently, conditional quantile estimations provide information, which is not accessible with conditional mean estimations.

The remainder of the paper is organized as follows. Section 2 briefly reviews related literature pertaining to the EKC hypothesis. Section 3 outlines the data and methodology. Section 4 presents and discusses the results of the estimations while section 5 makes conclusion and policy implications based on the empirical findings.

2. Review of related literature

The EKC literature is quite extensive and continually expanding. The methodology made its debut through the seminal paper of Grossman and Krueger (1991) in which they analyzed the relationship between per capita GDP and a selected set of pollutants notably SO_2, suspended particles and dark matter. They employed a pooled cross-sectional data and uncovered both an N-shaped and an inverted U-shaped relationship between the selected pollutants and per capita GDP in different model specifications. The inverted U-shaped relationship is analogous to that depicted by Kuznets (1955, 1963) who also hypothesized an inverted U-shape between the level of income and income distribution (income inequality) thus earning it the name "Environmental Kuznets Curve". Suri and Chapman (1998) have also found an inverted U-shaped relationship between per capita GDP and per capita energy consumption whilst also controlling for the export and import share of the manufacturing sector. Their study showed that the quadratic GDP term might be a catchall for the structural transformation of the economy from the agricultural sector to the pollution-intensive industrial sector, to the less pollution-intensive service sector. The structural transformation of an economy might also bring with it changes to the structure of trade flows as service-based economies may have a higher import content than industry-based economies which might have a higher export content that may have a part to play in the EKC hypothesis (Stern, 2004; Cole,2004). Trade is found to be one of the significant factors that influence the shape of the EKC. The pollution haven hypothesis (PHH) implies a situation where as a result of less stringency in institutional regulations as regards to "cleaner" production practices in the developing countries, industries may tend to absorb "dirtier" industries from the developed countries while the developed countries adopt cleaner production practices due to institutional pressures. An attempt to offer the PHH as an explanation for the EKC hypothesis by a few studies came up with very little evidence (Cole, 2004; Kearsley & Riddel, 2010).

The institutional dimension of the EKC paradigm has also been explored in a study by Lau et al. (2018) where they revealed the pollution abatement effect of institutional quality. Specifically, they discovered that the control of corruption and rule of law mitigates the proliferation of environmental pollutants in the high-income countries. This result corroborates Mavragani et al. (2016) which uncovered a positive correlation between institutional quality and environmental performance index for a panel of 75 countries comprising the G20 and EU economies. In contrast Sulemana et al. (2017) while validating the EKC hypothesis in both African and developed economies posited an insignificant effect of institutions on emissions in both samples of countries. They also discovered a positive effect of democracy on emissions in African countries. Similarly, Usman et al. (2019a) recently revealed that a negative effect of democracy on CO_2 emissions within the periods 1971 and 2014 for India. However, the negative effect was only significant in the short run. These mixed results are suggestive that the institutional effect of pollution abatement (proliferation) is probably dependent on a country's developmental stage. As such, the development stage of the countries needs to be taken into consideration when empirical analyses of this nature are being undertaken especially in panel studies.

Development stages of each country would also reflect in their emissions levels; hence, studies incorporating individual heterogeneity as well as distributional heterogeneity across the conditional quantiles of the pollutant's distribution need to be considered in panel studies. One of such studies is Wang (2013)

[1] The period chosen is apparently influenced by the data availability.

who employed a dataset of 138 countries within the periods 1971 and 2007 and found that the long-run elasticity between income and CO_2 emissions declines across the conditional distribution of CO_2 emissions showing a transition from cross-coupling to relative-decoupling and from lower to higher quantiles. Their result also showed that the short-run adjustment coefficient increases speed and gains more stability as the value of the quantiles increases. This might imply that the income-CO_2 relationship attains steady state only at higher quantiles. Employing data for a different set of pollutants (NO_x and SO_2) across 48 States in the U.S within the periods 1929 and 1994, Flores et al. (2014) found an N-shaped relationship between Nitrogen Oxide (NO_x) and income, which is only significant from the 1st to 5th quantile. Their result also showed a significantly positive income-SO_2 relationship albeit with significant evidence for the EKC hypothesis occurring at only the median quantile. The contrast in the last two reviewed studies is probably due to the choice of pollutants and geographical locations. Cheng et al. (2018) found a negative relationship between per capita GDP and carbon intensity in 28 EU countries across all quantiles. They utilized the panel quantile regression estimator and found a negative relationship between oil price and carbon intensity which is asymmetrically shaped in an inverted-U form across quantiles. Cheng et al. (2019) employed panel quantile estimators as well as ordinary least squares methods (OLS) to identify the heterogeneous impacts of renewable energy, environmental patents, economic growth and other selected variables on CO_2 emissions in BRICS countries. They found heterogeneous impact of the exogenous variables across the conditional distribution of CO_2 emissions. In addition, Yan et al. (2019) used panel quantile regression methods in order to quantify the determinants of total factor energy efficiency in 105 resource-dependent Chinese cities. Their analysis showed that the coefficient estimates of all determinants were disparate across quantiles. The degree to which foreign capital is utilized in fixed capital had a negative effect on total factor energy efficiency across all but the 1st quantile. This gives part validation for the pollution haven hypothesis. Yaduma et al. (2015) applied the fixed effects panel quantile regression on OECD and non-OECD countries across six geographical regions of the world. Their study uncovered coefficient estimates and EKC characteristics that are disparate across regions. Zhu et al. (2016) also employed the fixed effects panel quantile regression to investigate the impact of income, energy consumption, foreign direct investment (FDI), trade and other control variables on CO_2 emissions in 5 ASEAN countries over the periods 1981 till 2011. The results indicated a significantly positive monotonic relationship between GDP and CO_2 emissions that persists from the 5th quantile up until the 70th quantile. The relationship, however, becomes U-shaped at the 95th quantile. Mishra et al. (2015) went a step further to augment their model with institutional quality proxied by democracy (Polity 2), democratization and bureaucratic quality in a panel of 127 countries for the periods 1960–2003. Although they found a significantly negative relationship between their proxies for institutional quality and pollutant emissions (SO_2 and CO_2), their income-pollutant emissions relationship evinced different curve characteristics at lower and upper quantiles. Their model also lends credence to the pollution haven hypothesis due to a statistically significant positive trade coefficient across all quantiles.

Following the literature we have reviewed, our study is not only motivated by the paucity of literature in the context of oil production-induced CO_2 emissions but also contributes to the existing literature by incorporating and testing the EKC hypothesis considering the developmental stages of the countries which reflects in their emissions levels. Hence, the recently developed Method of Moments Quantile regression technique of Machado and Silva (2019) is employed. Our model estimation also incorporates the effects of democratic regime, electricity consumption, and trade in the income-environmental degradation nexus for the panel of oil-producing countries between 1980 and 2010.

3. Data and methodology

To achieve the objective of this study, we obtained annual data from the World Bank - World Development Indicators' databank (WDI), the Polity IV database, and the US Energy Information Administration (EIA) for the period 1980 to 2010, and constructed a panel for the countries used. The data, unit of measurements, transformation, and their sources are tabulated and shown in Table 1.

3.1. Summary statistics

Generally, From Table 2, the dataset appears to be fairly symmetric. It can be observed from Table 2 that the variables exhibit positive and negative skewness. Particularly, the CO_2 emission, democracy and real GDP are negatively skewed while oil production, electricity production, and trade are positively skewed. Democracy has the lightest tails due to its very low kurtosis and

Table 1
Data, Units, Transformations and Sources.

Data	Measurement Unit	Transformation	Source
GDP per capita	Constant 2010 USD	Natural logarithm Transformation	WDI, (2013)
CO_2	Metric tons per capita	Natural logarithm Transformation	WDI, (2013)
Democracy	Polity2 Index measured from −10 (most autocratic) to + 10 (most democratic).	Transformed to values ranging from 0 to 20 to remove negative numbers. A higher value indicates a more democratic regime and vice versa.	Polity IV dataset http://www.systemicpeace.org/polity/polity4.htm.
Electricity Production	Kilowatt-hour per capita	Natural logarithm Transformation	WDI, (2013)
Oil production	1000 barrels per day	Multiplied by 365 to obtain average annual rates and divided by the population to obtain per capita values. The data is transformed to the natural logarithm.	U.S Energy Information Administration (EIA) 2018
Trade	Percentage of GDP	Multiplied by real GDP and divided by 100 to obtain real aggregate values. The values are divided by population to obtain per capita values. The data is transformed to the natural logarithm	WDI, (2013)

Table 2
Summary Statistics.

Variables	Mean	Std. Dev.	Min	Max	Skewness	Kurtosis
CO_2 emissions	−5.30	1.07	−8.0	−3.4	−0.39	2.46
Democracy	21.85	7.76	10	30	−0.29	1.33
Real GDP	9.20	1.26	5.85	11.42	−0.29	2.27
Oil production	−9.99	1.61	−13.1	−6.6	0.20	2.54
Electricity production	7.83	1.53	3.92	10.3	0.33	2.40
Trade	8.36	1.54	3.76	11.12	0.20	2.50

Note: The values are from already transformed variables.

has the most volatile by virtue of its high standard deviation with the implication of higher dispersion of data points.

3.2. Panel estimation techniques

For comparative purposes, we employ the Fully Modified Ordinary Least Squares (FMOLS), the Dynamic Ordinary Least Squares (DOLS) and the Fixed Effects Ordinary Least Squares OLS (FE-OLS). The FE-OLS technique is augmented with Driscoll and Kraay standard errors, which are robust to general forms of cross-sectional dependence and autocorrelation up to a certain lag. The central reasons for concern in estimating dynamic cointegrated panels as highlighted by Pedroni (2004) are heterogeneity issues with differences in means between cross-sections and differences in cross-sectional adjustment to the cointegrating equilibrium. Pedroni's FMOLS model includes individual-specific intercepts and allows for heterogeneous serial correlation properties of the error processes across individual members of the panel, and thus, deals with these issues accordingly. The DOLS estimator was extended to panel data settings by Kao and Chiang (2001) based on the results of Monte Carlo simulations, the DOLS estimator was found to be unbiased compared to both OLS and the FMOLS estimators in finite samples. The DOLS estimator also controls for endogeneity through the augmentation of lead and lagged differences to suppress the endogenous feedback.

Due to the limitations of previous estimation methods, a panel quantile regression technique was employed to examine the distributional and heterogeneous effect across quantiles (Sarkodie and Strezov, 2019). The panel quantile regression method was introduced by the seminal paper of Koenker and Bassett (1978). Generally, the quantile regressions are utilized to estimate the conditional median or a variety of different quantiles of the response variables subject to certain values of the exogenous variables unlike regular regressions of the least-squares variant, which yield estimates of the conditional mean of the endogenous variable subject to certain values of the exogenous variables. Quantile regressions are more robust to incidences of outliers in the estimation. Aside from that, it is the most pertinent in cases where the relationship between the conditional means of two variables is weak or non-existent (Binder & Coad, 2011).

However, in this present study, we employed the Machado and Silva (2019) Method of Moments Quantile Regression (MMQR) with fixed effects. A quantile regression whilst being robust to outliers does not consider possible unobserved heterogeneity across individuals within a panel. The MMQR method makes it possible to identify the conditional heterogeneous covariance effects of the determinants of CO_2 emissions by allowing the individual effects to affect the entire distribution rather than just shifting means as in the case of Koenker (2004), Canay (2011) amongst others. The MMQR estimation technique is particularly relevant in scenarios where the panel data model is embedded with individual effects and when the model possesses endogenous explanatory variables. The MMQR approach is also quite intuitive because it yields non-crossing estimates of the regression quantiles. The estimation of the conditional quantiles $Q_Y(\tau|X)$ for a model of the location-scale variant takes the following form:

$$Y_{it} = \alpha_i + X_{it}{}'\beta + \left(\delta_i + Z_{it}{}'\gamma\right)U_{it} \quad (1)$$

where the probability, $\mathrm{P}\{\delta_i + Z_{it}{}'\gamma > 0\} = 1.(\alpha,\beta',\delta,\gamma')'$ are parameters to be estimated. $(\alpha_i,\delta_i), i = 1,\ldots,n,$ designates the individual i fixed effects and Z is a k-vector of identified components of X which are differentiable transformations with element l given by:

$$Z_l = Z_l(X), l = 1,\ldots,k \quad (2)$$

X_{it} is independently and identically distributed for any fixed i and is independent across time (t). U_{it} is independently and identically distributed across individuals (i) and through time (t) and are orthogonal to X_{it} and normalized to satisfy the moment conditions in Machado and Silva (2019) which amongst other things do not imply strict exogeneity. Eq. (1) implies the following;

$$Q_Y(\tau|X_{it}) = (\alpha_i + \delta_i q(\tau)) + X_{it}{}'\beta + Z_{it}{}'\gamma q(\tau) \quad (3)$$

From Eq.(3), $X_{it}{}'$is a vector of independent variables which in the present study are the natural logarithm of GDP per capita (LGDP), the natural logarithm of squared GDP($LGDP^2$), democracy (DEMOC), the natural logarithm of oil production per capita (LOILPD), the natural logarithm of electricity production per capita (LELEPD) and the natural logarithm of trade per capita (LTRD).$Q_Y(\tau|X_{it})$ indicates the quantile distribution of the dependent variable Y_{it} (natural logarithm of CO_2 emissions per capita) which is conditional on the location of independent variable X_{it}.-$\alpha_i(\tau) \equiv \alpha_i + \delta_i q(\tau)$ is the scalar coefficient which is indicative of the quantile-τ fixed effect for individual i. The individual effect does not denote an intercept shift, unlike the usual least-squares fixed effects. They are time-invariant parameters whose heterogeneous impacts are allowed to differ across the quantiles of the conditional distribution of the endogenous variable Y. $q(\tau)$denotes the τ-th sample quantile which is estimated by solving the following optimization problem;

$$min_q \sum_i \sum_t \rho_\tau\left(R_{it} - \left(\delta_i + Z_{it}{}'\gamma\right)q\right) \quad (4)$$

where $\rho_\tau(A) = (\tau - 1)AI\{A \leqslant 0\} + TAI\{A > O\}$ denotes the check function.

4. Empirical results

4.1. Cross-sectional dependence and unit root tests

Before estimating the unknown parameters, some standard preliminary tests are undertaken in order to ascertain the time series properties of the variables. We first check the existence of cross-sectional dependence (CD) within the panel. Cross-sectional dependence can distort the true parameter values of coefficient estimates. Cross-sectional dependence which may arise as a result of unobserved common factors can greatly diminish panel data efficiency gains if ignored (Phillips & Sul, 2003). It is, therefore, important to consider this issue in order to produce robust coefficient estimates. We employ the Pesaran (2004) CD test in order to assess cross-sectional dependence within the panel. From Table 3, apart from oil production, all the other quantitative variables exhibit significant cross-sectional dependence across countries. Thus, our unit root and cointegration tests, as well as panel estimation techniques, must incorporate methodologies that are robust to the effects of cross-sectional dependence in order to mitigate the potential size distortions.

Table 3
Cross-Sectional Dependence and Panel Unit Root Test Results.

Variable	LCO_2	LOILPD	DEMOC	LTRD	LELEPD	LGDP
Panel A: Cross-sectional dependence test						
Pesaran (2004) CD test	9.40***	1.23	–	33.3***	47.9***	30***
Panel B: Unit root tests						
Levels						
IPS (2003)	0.410	−1.046	−1.442	2.477	−0.264	1.108
Breitung (2001)	1.790	3.350	0.610	6.550	9.100	2.701
	1.8	3.35	0.61	2.7	9.10	2.7
Breitung & Das (2006)	−1.1301	−0.380	−0.080	2.601	5.440	1.200
	−1.1	−0.38	−0.08	1.2	5.44	1.2
First difference						
IPS (2003)	−18.237***	−12.128***	−5.719***	−10.525***	−16.033***	−15.522***
Breitung (2001)	−6.028***	−3.873***	−7.450***	−5.710***	−5.970***	−8.810***
	−6.0***	−3.9***	−7.5***	−8.8***	−5.97***	−8.8***
Breitung & Das (2006)	−4.205***	−3.700***	−10.300***	−3.430***	−7.120***	−1.920**
	−4.2***	−3.7***	−10.3***	−1.9**	−7.12***	−1.9**

Notes: *, ** and *** indicate significance at 10%, 5% and 1% levels.
Source: Authors' computations

In order to objectively assess the integrating properties of the investigated variables, we employ the Im, Pesaran and Shin (2003) (IPS), Breitung (2001) and the Breitung and Das (2005) panel non-stationarity tests. The Breitung (2001) and the Breitung and Das (2005) panel unit root tests assume a common autoregressive parameter for all individuals in the panel while the Im-Pesaran-Shin (IPS) (2003) test relaxes this assumption, and instead allows each individual to have its own autoregressive parameter. The Breitung (2001) panel unit root test has been shown to outperform other similar unit root tests in terms of power for moderately sized panel datasets such as the one employed for the present study. The Breitung and Das (2005) panel unit root test is a variant of the test that controls for cross-sectional dependence. We employ these three tests to ascertain the extent to which cross-sectional dependence affects the panel unit root tests. It can be observed from Table 3 that all the variables are non-stationary at levels but stationary at first differences in all unit root test specifications. This implies that all the variables used in the estimation are integrated of order one, I (1).

4.2. Panel cointegration test

In order to ascertain the existence of a non-spurious long-run relationship between the variables, we employ the Pedroni (2004) panel cointegration test and the Bootstrapped panel cointegration test of Westerlunds (2007). Pedroni (2004) proposes a comprehensive framework for panel cointegration testing under the spirit of the Engle and Granger 2-step methodology. Pedroni's approach filters out short-run parameters and individual-specific deterministic trends in the first step of the procedure, thus controlling for heterogeneity. Based on estimated residuals, Pedroni derives seven different test statistics, which can either be those assuming a common process, commonly denoted as "pooled" or "within-dimension" tests, and those assuming individual processes denoted as "grouped" or "between-dimension" tests. Under the Westerlunds (2007) technique, four new tests with the null hypothesis of no cointegration are proposed. The test relaxes the imposition of common factor restrictions on tests based on residual dynamics because these dynamics are structural in nature rather than residual. Structural dynamics are necessary because the failure of common factor restrictions can significantly reduce the power of residual-based cointegration tests (Kremers et al. 1992).

Table 4
Panel Cointegration Tests.

Panel A: Pedroni (2004) residual-based test for cointegration				
Statistic	Panel-PP	Panel-ADF	Group-PP	Group-ADF
Values	−2.262**	−2.683***	−6.466***	−5.988***
Weighted values	−2.041**	−5.223***		
Panel B: Westerluns (2007) Bootstrapped error correction based cointegration test				
Statistic	Pτ	Pα	Gτ	Gα
Values	−9.419	−4.500	−2.400	−5.076
P-values	0.160	0.992	0.540	1.000
P-values (Robust)	0.022**	0.215	0.042**	0.205

Notes: ***, ** indicate the significance of the cointegration test at 1% and 5% levels. Panel PP and group PP statistics indicate the Phillips and Perron panel and group statistics. Panel ADF and Group ADF statistics indicate the augmented Dickey and Fuller panel and group statistics

With the removal of this restriction, long and short-run adjustment processes need not be identical. Employing the bootstrap approach of Westerluns (2007), we can mitigate the distortionary effects of cross-sectional dependence and thus produce robust critical values. The results from Table 4 shows that both the Pedroni (2004) test and the Westerluns (2007) bootstrapped cointegration test provides robust support for cointegration.

4.3. Panel estimation results

The results from FMOLS, DOLS and FE-OLS estimation procedures are presented in Table 5. From Table 5, we observe that the coefficient estimates obtained from all three specifications

Table 5
Panel Estimation Results.

Variables	FMOLS	DOLS	FE-OLS (D-K S.E)
LGDP	1.236***	0.737	0.925***
$LGDP^2$	−0.031*	−0.018	−0.024**
DEMOC	0.005***	0.003	0.005
LOILPD	0.189***	0.273***	0.083***
LELEPD	0.382***	0.413***	0.324***
LTRD	−0.316***	−0.330***	−0.218***

Notes: ***,**,* indicate the significance of the cointegration test at the 1%, 5% and 10% levels.

are on the average, quite close to each other even though they all vary in terms of statistical significance. Electricity production and trade are the most robust across all three specifications in terms of statistical significance and coefficient size. A percentage increase in electricity production positively impacts CO_2 emissions by ~0.32% in the case of the FE-OLS estimator and ~0.41% in the case of the DOLS estimator. Trade, on the other hand, exerts a significantly negative impact on the level of CO_2 emissions. Put differently, a percentage increase in trade mitigates emissions by ~0.33% in the case of the DOLS estimator. This validates the pollution halo hypothesis for the panel of oil-producing countries. This result echoes the major conclusion of Nasir and Rehman (2011) but contradicts Ozatac et al. (2017) who found a positive and inelastic impact of trade on CO_2 emissions in Turkey. More so, democracy is seen to have a positive effect, which is only significant in the FMOLS estimation specification. This finding contradicts Usman et al. (2019a) but aligns with the theory of modernization. There is a weak statistically significant support for the EKC hypothesis in the FMOLS specification and a strong statistically significant support in the FE-OLS estimation specification, but no statistically significant evidence is found in the DOLS specification even though the curve is visible. Oil production as expected exhibits a positive statistically significant relationship with CO_2 emissions, but its coefficient seems disparate across specifications, ranging between 0.083% and 0.273% increase in CO_2 emissions for a percentage increase in oil production for the FE-OLS and DOLS estimators, respectively.

From Table 6, the panel quantile regression estimates show that the effect of oil production on CO_2 emissions is statistically significant from 1st to 6th quantiles, while at higher quantiles (i.e. 7th, 8th, and 9th quantiles) the effect of oil production is insignificant. This result validates the effectiveness of environmental policies pertaining to oil production at higher polluting countries. The effect of income captured by GDP on CO_2 emissions is significant across all quantiles with the EKC hypothesis being validated from 4th to 9th quantiles and being strongly validated from the median to 9th quantile. The results show that the EKC hypothesis is only valid in countries with median to above-median CO_2 emissions. This implies that at countries below the median, development is prioritized above environmental quality. Also, countries below the median being at lesser developmental stages by virtue of their emissions level may find it more challenging to switch fuels from renewable to non-renewable sources due to the investment cost implication. Oil production has no positive effect on CO_2 emissions in countries with the highest emissions level. This may stem from the different extraction practices obtainable in developed and developing oil-producing economies. These results portend serious implications for policy which concurs with Shahbaz et al. (2017) and Sarkodie and Strezov (2018) who validated the EKC hypothesis for China, which emits very high levels of GHGs and carbon dioxide. Our finding is also congenial to the recent empirical study by Usman et al. (2019a) who confirmed the EKC hypothesis in India, another top emitter of CO_2. The results are also consistent with Rafindadi and Usman (2019) who established the presence of the EKC hypothesis for the largest emitter of GHGs and CO_2 in Africa. The results based on democracy, however, showed that its effect on CO_2 emissions is positive in all the quantiles but only statistically significant in the average CO_2 emissions countries (i.e. 3rd, 4th and 5th quantiles). This finding could be attributed to the positive correlation between democracy and income, a cornerstone of the theory of modernization. Therefore, it is not consistent with Farzin and Bond (2006) and Usman et al. (2019a) who posited that the freedom of the people in democracy pushes the government and its managers to pursue environmentally-friendly policies. As expected, the impacts of oil production and electricity production on CO_2 emissions are positive. Specifically, while the impact of electricity production is highly significant in all the quantiles, it is evident that the impact of oil production is only significant in the lower and average quantiles, suggesting that these countries are obviously advancing towards reducing oil producing-induced emissions. Finally, our quantile results revealed a negative and significant relationship between trade and CO_2 emissions. This finding agrees with Nasir and Rehman (2011) and disagrees with Cole (2004) as well as Ozatac et al. (2017) who argued that trade gives room for the penetration of unclear industries in countries with less stringent environmental laws, causing a pollution haven hypothesis. The results based on the location and scale parameters succinctly show that while democracy may not significantly affect the average CO_2 emissions, it, however, has a higher negative dispersion across quantiles. Meaning that, democracy has an increase variance across quantiles as depicted in Fig. 1. The EKC hypothesis is not only observed from the locational dimension but also from the dimension of dispersion, as both LGDP and $LGDP^2$ are significantly dispersed across quantiles as observed in Fig. 1.

5. Conclusion and policy implications

As a contribution to the energy and environment-related literature on environmental pollution in the light of oil production and economic development, this study investigates the empirical relationship between oil production, electricity production, trade, democracy, GDP and CO_2 emissions whilst accounting for the EKC hypothesis. We employed panel unit roots, panel cointegration and panel estimation techniques with data spanning over 30 years in 15 oil-producing countries. The quantitative variables (except democracy) were all measured in per-capita terms to control for population. Panel unit root and panel cointegration techniques showed that the variables all follow an I(1) process with the existence of a non-spurious long-run relationship between these variables. Traditional panel cointegration estimation techniques showed disparities in coefficient significance even though the sizes obtained from the different specifications are not too far apart. We

Table 6
Panel Quantile Estimation Results.

Variables	Method of Moments Quantile regression with fixed effects										
	Location	Scale	Quantiles								
			0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
LGDP	0.925*	0.209***	0.612*	0.687***	0.768***	0.853***	0.929***	0.999***	1.080***	1.145***	1.209***
$LGDP^2$	−0.023	−0.015***	−0.001	−0.007	−0.012	−0.019*	−0.024***	−0.029***	−0.035***	−0.039***	−0.044***
DEMOC	0.005	−0.002*	0.008	0.008	0.007*	0.006*	0.005*	0.004	0.004	0.002	0.002
LOILPD	0.083	−0.029	0.127*	0.117*	0.105***	0.093***	0.083**	0.073*	0.061	0.052	0.044
LELEPD	0.324***	−0.025	0.361***	0.352***	0.343***	0.332***	0.323***	0.315***	0.305***	0.297***	0.289***
LTRD	−0.218***	0.027	−0.258***	−0.249***	−0.238***	−0.227***	−0.216***	−0.208***	−0.198***	−0.190***	−0.181***

Notes: *,** and *** indicate significance at 10%, 5% and 1% levels, respectively.
Source: Authors' computations

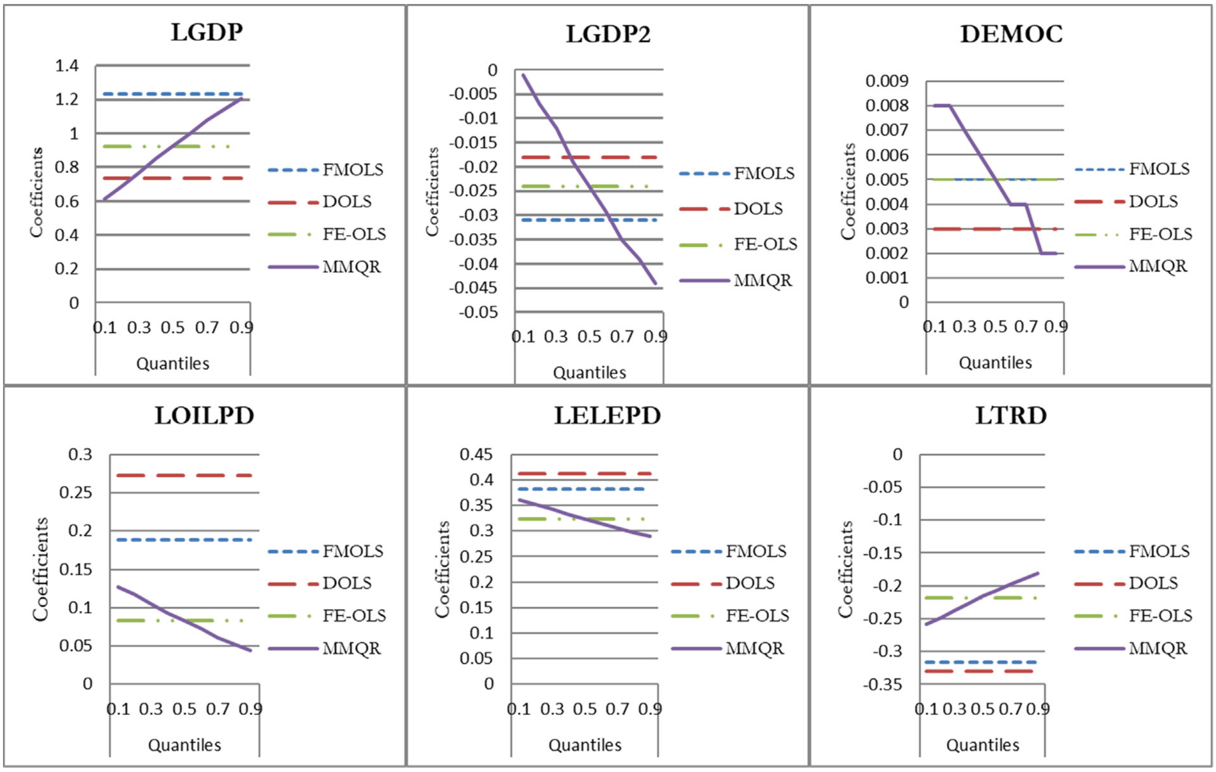

Fig. 1. Graphical representation of coefficient estimates for all variables across all quantiles, obtained from all 4 estimators.

utilized the MMQR technique which allows for the analysis of the different impacts of the exogenous variables across different quantiles of the conditional distribution of CO_2 emissions, useful for a more robust assessment of the empirical relationship.

The coefficient estimates of FMOLS, DOLS, and FE-OLS validated the EKC and Pollution Halo hypotheses for oil-producing countries. Our findings from the MMQR revealed that oil production is positively significant from the 1st to 6th quantiles while democracy is positively significant from the 3rd to median quantiles which implies that the positive relationship between oil production and CO_2 emissions are only felt at the lower quantiles of the conditional distribution of CO_2 emissions. This may probably imply that oil production has a positive effect in oil-producing countries at their early and transitional development stages while democracy only statistically increased CO_2 emissions in quantiles close to the median. It is noteworthy to point out that more developed oil-producing economies with higher emissions are more economically diversified than their developing counterparts who are much more dependent on oil extraction. This implies that oil may probably account for a relatively smaller share of their emissions profile. A visual inspection of Fig. 1 showed that the MMQR estimates of oil production (LOILPD) and income (LGDP) follow different dynamics. The estimate of oil production had its highest coefficient at the lowest quantile while that of income had the highest coefficient at the highest quantile. While the coefficient of oil production reduces from the lowest to highest quantile, the coefficient of income increases from the lowest to the highest quantile. This implies that CO_2 emissions are at their lowest levels at quantiles where oil production effects on emissions are highest and economic growth (income) effects on emissions are lowest. On the contrary, at quantiles where CO_2 emissions were highest, the reverse scenario occurred. This entails that more overall production occurs at countries that are least dependent on oil production. Dependence, in this case, does not necessarily imply abundance. This gives yet another evidence for the de-industrialization induced resource curse. The insignificance of the positive impact of democracy in the higher quantiles could be traced to the recent government environmental policies towards circumventing the continuous proliferation of the GHGs and CO_2 emissions. Environmental quality has relatively more importance to citizens of countries with higher emissions compared to their lesser emissions counterparts. Thus, democratic regimes which conform to the will of the people would deploy more policies towards emissions abatement in order to gain the goodwill of the electorate. The fact that pollution abatement policies may be detrimental to growth, democratic regimes in the higher emission countries may also be open to a lot of compromises, thus, the insignificance of democracy at higher emission quantiles. At quantiles close to the median where democracy has a significant positive impact on carbon emissions, environmental quality may not be too much of a concern to citizens of these countries because the effects of environmental degradation may not be immediately visible. Thus, economic growth which may be reliant on emissions dependent production activities may be given more priority by the electorate and the elected. At lower emission countries, the effect of democracy may not be felt due to the preponderance of oil extraction activities and a higher presence of the resource curse. The positive and insignificant effect of democracy in the higher quantiles is indicative of improvement in the democratization process of the oil-producing countries. The experience of India as documented by Usman et al. (2019a), Romania documented by Shahbaz et al. (2013) and emerging countries documented by Lv (2017) is an assurance that improving the level of democracy would reduce emissions. Therefore, we suggest the need to improve the degree of democratization in oil-producing countries, especially in oil-producing countries with high atmospheric emissions.

Electricity production was positive and significant across all quantiles while trade had a negative relationship with CO_2 emissions across quantiles. This result validates the pollution halo hypothesis in the existing literature. Within the context of oil-producing countries, the findings may imply different causes for different quantiles. At lower quantiles, a possible cause would be the effect of de-industrialization, a condition that occurs when oil production crowds out all the other emissions dependent tradable sectors of the economy. This condition consequently makes them more import-dependent, thus, a significant amount of their trade will be composed of imports and oil exports. At higher quantiles, the movement of labour-intensive export-oriented industries from higher-wage economies to lower-wage economies in order to increase profits may tilt the trade dynamics towards imports and significantly cut down emissions levels in these countries. Also, at higher emission countries the effect of the pollution halo hypothesis may apply directly due to the stringency of environmental laws on emissions dependent export-oriented industries. This situation may force onshore industries to cut down on their emissions production. Due to the cost implication of employing improved energy efficiency technologies and fuel switching, in a bid to appropriate more profit, a lot of firms may reallocate their firms to an overseas location with less stringent environmental policies. Electricity production affects all the productive sectors of the economy and thus expected to be positively related to carbon emissions. From Fig. 1, however, it was observed that the effect of electricity production on carbon emissions is highest at the lowest quantile and lowest at the highest quantile. This does not necessarily imply a reduction of productivity from the lowest to the highest quantile but an increase in energy efficiency from the lowest to the highest quantile as less CO_2 emissions are produced per unit of energy produced due to more efficient energy systems. It may also imply the effect of switching from non-renewable to renewable electricity production sources at higher emissions countries that can afford the investment cost implications. The fact that electricity production remains significantly positive relative to CO_2 emissions may imply that electricity production in these countries is from both renewable and non-renewable sources. The implication of this result is that to reduce the level of CO_2 emissions in the oil-producing countries, more effort should be put in place to reduce electricity production from fossil fuel energy sources. In other words, electricity production from clean and renewable sources like hydropower, wind, solar and nuclear power, etc. should be encouraged. Better still, where the countries have no sufficient resources to embrace renewable electricity generation, such countries should embrace moderate environmental tax policies. These policies entail the moderate taxation of emissions dependent industries. The revenue accrued from such taxes should be re-invested in long-term infrastructural development of renewable energy sources.

Declaration of Competing Interest

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

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