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Impacts of Environment-Related Technology, Structural Change, and Globalization on Greenhouse Gas Emissions: Evidence from Top Twenty Emitter Countries

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ABSTRACT

The issues of environmental degradation, climate change, and rising temperatures are a real and growing concern for humanity at the level of individuals, groups, and societies. Reducing greenhouse gas is an important element for nations to achieve their ambitious climate-resilient growth goals. The purpose of this research is to investigate the impact of environment-related technology, structural change, income, and globalization on greenhouse gas emissions in the top twenty emitter countries from 1997 to 2019. To this end, this study has applied the new and widely used method of moment quantile regression to permit the estimation of relationships across the distribution of an outcome. In order to test the reliability of the benchmark estimation results, this article uses three different methods for robust testing, the panel-corrected standard errors, feasible general least square and the linear regression with Driscoll–Kraay standard errors. The main findings of this paper show that environment-related technology, structural change, and globalization helps to boost ecological quality. Moreover, there is strong evidence on the existence of an N shape Environmental Kuznets Curve. Based on the findings of this paper, governments should encourage investment in environment related technology and post the transition to services-based economies.

Keywords: Green House Gas, Globalization, Services Sector, Electrical Resistivity Tomography, High Emitters
JEL Classifications: Q5, P42, Q14, F64

1.INTRODUCTION

The negative repercussions of climate change on various aspects of life occupy a wide interest at the level of individuals, organizations, and countries. This is what drives researchers and policy planners in the fields of environment, economics, politics, and society to search for the sources of these emissions for the purpose of reducing them and also on the factors that can contribute to controlling these emissions in order to activate them and contribute to achieving the requirements of sustainability.

The issues such as environmental degradation, climate change, and rising temperatures are a real and growing concern for humanity at the level of individuals, groups, and societies. The issue of addressing these challenges has become a given and depends on the ability to overcome them and sustain the basic necessities of life.

The relationship between economic growth and environmental degradation (the increase GHG emissions) is well documented in the literature. The trade-off between economic growth and environmental degradation has been subject to a large bulk of studies. However, the EKC hypothesis is the most acceptable theoretical base to the nature of this relationship, and it has been adopted by large number of empirical studies. Grossman and Krueger (1995) find the long-term relationship between environmental quality and economic growth is an inverted

U-shaped curve. The idea behind this relationship is as follow: as the economy move from primary sector (agriculture) to the industrial sector, which is catheterized to be energy intensive the quality of environment mitigated. Furthermore, as the economy shift to the service (or tertiary) sector the quality of environment will improve. The service (or tertiary) sector is generally recognized as a relatively the cleaner part of the economy. Accordingly, sustainable development coincides with a shift from primary and secondary sectors to the tertiary sector. Accordingly, it seem that "structural change hypothesis", is a core part of the Environmental Kuznets Curve (EKC) hypothesis Kaika and Zervas (2013).

Studies on the globalization GHG emission nexus do not have a unified conclusion. In fact, there are two viewpoints regarding this issue. The first viewpoint gives a constructive role to globalization in GHG mitigation. The justification to this viewpoint is based on the ability of globalization to improve resource utilization efficiency by stimulating technological progress. The second viewpoint assigned a destructive role to globalization. The idea behind the second viewpoint is based on the belief that foreign trade has a negative impact on a country's environment that surpasses its economic development Greenford et al. (2020).

The research is planned as follows; after this introduction, we present a review of the literature related to the variables of our interest. In the section follow an overview of the data, model, the structure of empirical work, and description of used research motherhoods, as well as formulation of the hypothesis and its novelty will be presented. After that the obtained results and their explanation are presented in section. In the last section we present the conclusions as well as the suggestions for the application of the findings.

2. LITERATURE REVIEW

During the first two decades of the current century, there is an increasing interest in investigating the role that environment-related technology can play in mitigating greenhouse gas. However, despite the growing attention on those roles, there is a desperate need for examining those roles especially when comes to the top twenty emitter countries. Moreover, we find that studies focusing on the importance of structural change in improving the environment are still rare. This study aimed to contribute in filling the gap. Table 1 present a summary of the literature focusing on the variables included in our study.

3. DATA, MODEL, ESTIMATION METHODS

3.1. Data

Data are collected from the World Development Indicators (WDI, 2022), KOF Swiss Economic Institute, and OECD. Stats. Our dataset consists of Top 20 greenhouse gas emitter Countries, namely Argentina, Australia, Brazil, Canada, China, France, Germany, India, Iran, Islamic Rep., Italy, Japan, Korea, Rep., Mexico, Poland, Russian Federation, Saudi Arabia, South Africa, Turkey, United Kingdom, United States. To this end, this study used annual data stretching from 1997 to 2019. Details of variables are reported in Table 2. Descriptive statistics are presented in Table 2.

3.2. Model

This study aims to evaluate elasticities between Environment-Related Technologies, Structural Change, Globalization and Greenhouse Gas Emissions within the EKC framework. As stated before, including Sahoo et al. (2022); Shahbaz et al. (2020); Behera and Pozhamkandath (2021); and Le (2021); the empirical model used in this study can be specified as:

$$LnGHGem_{it} = f(LnGDPpc_{it}, LGDPpc2_{it}, LGDPpc3_{it}, LnENVRtech_{it}, LnSTCH_{it}, LnGLOB_{it}) \quad (1)$$

The econometrics model of Equation (1), which is in line with Kuznets' environmental hypothesis of the form N, is identified as:

$$LnGHGem_{it} = \beta_{it} + \beta_1 LGDPpc_{it} + \beta_2 LGDPpc2_{it} + \beta_3 LGDPpc3_{it} + \beta_4 LnENVRtech_{it} + \beta_5 LnSTCH_{it} + \beta_6 LnGLOB_{it} + \varepsilon_{it} \quad (2)$$

Where β_{it} are the constant terms; β_i represent the elasticity of the dependent variable with respect to the corresponding independent variable; ε_{it} are the residual terms. i and t represent panel countries (i = 1,…,N) and time (t = 1,…,T).

Moreover, the following statistical hypotheses on the Kuznets curve were considered. These hypotheses are:

1. When the EKC model fulfills the constraint $\beta_1 > 0$ and $\beta_2 = \beta_3 = 0$, then the relationship between the variables is linear and direct, so economic growth implies a greater deterioration of the environment (increasing monotone relationship).
2. When the fitted model presents $\beta_1 < 0$ and $\beta_2=\beta_3=0$ as results, the relationship is then linear and inverse. As for greater growth, there will be a decrease in pollution levels (decreasing monotonous ratio).
3. When the parameters obtained are $\beta_1 > 0$, $\beta_2 < 0$ and $\beta_3 = 0$, there is an inverted U shape (existence of a Kuznets curve).
4. When $\beta_1 > 0$, $\beta_2 < 0$ and $\beta_3 > 0$, the shape of the EKC will be an N shape. Therefore, after a certain high level of income, a positive relationship between environmental degradation and economic growth occurs again (Allard et al., 2018).
5. Regarding hypotheses postulated on the impact of other explanatory variables on emissions, we expected that $\beta_4 < 0$. $B_5 < 0$ and $\beta_6 < 0$. As for higher level of globalization, moving from industrial sector to services sector and more application of environment related technology, there will be a decrease in pollution levels.

3.3. Estimation Methods

The panel used in this paper has a relatively small number of cross sections (N = 20 countries) and time dimensions (1997–2019, i.e., T = 23 years). Since there is a violation of the normality assumption, this study applies method of moment quantile regression (MMQREG) as a preferred estimation method. The choice of MMQREG backed by: First, unlike least squares regression, quantile regression does not assume a particular

Table 1: Review of literature

Author (s)	Method	Period	Region, Country	Variable	Result
Lin and Wu (2022)	Q. Regression	2004–2019	7 emerging count	Glob.	Increase
Shahzad et al. (2022)	VAR model	1996–2019	China	Financial Glob.	Reduce
Adebayo et at., (2023)	NARDL	1965–2O19	Turkey	STCH (serv.)	Reduce
Xia et al. (2022)	Panel Regression	1971–2018	67 countries	Glob.	Increase
Ullah et al. (2021)	ARDL	1990–2017	Pakistan	Glob.	Increase
Xu et al. (2022)	ARDL	1970–2019	Brazil	Financial glob.	Increase
Khan et al. (2022)	FMOLS	1972–2017	South Asian Countries	Glob.	Increase
Muzzammil et al. (2022)	ARDL (CS-ARDL)	1990–2016	7 emerging economies	Env. Rel. Tech	Reduce
Ali et al. (2017)	ARDL	1980–2016	Malaysia	STCH (ind.)	Increase
Ali et al. (2020)	ARDL and DOLS	1971–2013	Malaysia	8TCH (ind.)	Increase
Alam (2010)	Multiple Regression	1972–2010	Bangladesh	STCH (serv.)	Increase
Sahoo et al. (2022)	FMOLS, PCSE FGLS	1990–2018	14 Asian count	Tech. innov.	Reduce
Shahbaz et al. (2020)	ARDL	1984–201S	China	Tech. innov.	Reduce
Fernández et al. (2018)	OLS	1994–2013	USA, EU	R&D	Reduce
Kahouli (2018)	GMM	1990–2016	Mediterranean economies	R&D	Reduce
Kırıkkaleli et al. (2022)	Wavelet-based Tecb	1980–2017	South Africa	Glob and tech. innov.	Reduce

Table 2: List of variables, descriptions, and data sources

Variable	Definition	Data sources
LnGHGem	Total greenhouse gas emissions per capita	WDI
LnGDPpc	Gross Domestic Product (constant 2015 price US$)	WDI
LnGDPpc^2	Square of Gross Domestic Product	WDI
LnGDPpc^3	KOF economic globalization index	KOF
LnENVRtech	Environment-related technologies	OECD
LnSTCH	Services, value added (% of GDP)	WDI

WDI: World Development Indicators, KOF: Swiss Economic Institute, OECD: Organization of Economic Cooperation and Development

parametric distribution for the response, nor does it assume a constant variance for the response, and second the technique has become widely applicable to many research fields including ecological economics. However, according to Usman et al. (2022) one of the drawbacks of the MMQREG is that it failed to account for the cross-sectional dependence in the panel.

Furthermore, for checking the robustness of estimated results from the MMQREG approach, the Prais–Winsten regression with the panel-corrected standard errors (PCSE) model, feasible general least square (FGLS) model and linear regression with Driscoll–Kraay standard errors (D-K) are employed. The three robustness tests address the problems of autocorrelation, cross-sectional dependence and heteroskedasticity Le (2021).

3.4. Empirical Study Structure

In order to accomplish the objectives of the study we follow certain steps. Figure 1 depict the different steps followed in the empirical analysis.

4. PRELIMINARY ANALYSIS

4.1. Descriptive Statistics

We begin the empirical analysis by exploring the different properties of the studied variables. Descriptive statistics of the variables for our panel sample are shown in Table 3. The summary description for greenhouse gas shows that the skewness is -0.512, while the kurtosis is 3.553, showing a leptokurtic type, at the same time Jarque-Bera equal to 25.983 and significant at a 1 percent significance level.

Since one of the basic assumptions (normality assumption) of Ordinary Least Squares (OLS) does not hold, all the estimation techniques based on the OLS becomes not applicable. Thus, the panel quantile regression is employed to account for the heterogeneity of greenhouse gas emissions by quantiles.

4.2. Cross-Sectional Dependency Test

To scrutinize cross-sectional dependency, four tests are used: The Breusch and Pagan (1980), Pesaran (2020) scaled LM; bias-corrected scaled LM, and (Pesaran, 2020) CSD. Table 4 reports the test results.

4.3. Empirical Results from the Slope Homogeneity Test

Another important issue that should be considered for the application of the long panel data model is to check the slope homogeneity. In order to investigate the slope homogeneity among the cross-sections we applied Pesaran and Yamagata (2008) slope coefficient homogeneity (SCH) test. The null hypothesis of (SCH) test is slope coefficients are homogenous. Results of Δ and Δ_{adj} statistics level (Table 5) expose that the null hypothesis of slope homogeneity is rejected at a 1 % significant.

4.4. Panel Unit Root Test

Taking the presence of cross section dependence in consideration, this study employs the panel unit root test proposed by Pesaran (2007) to identify the stationarity properties of the variables. CIPS test is an efficient second-generation unit root test as it considers both the cross-section dependency and heterogeneity issues. The null hypothesis of CIPS unit root test is that the unit root exists in the panel data and the alternative hypothesis assumes stationarity.

Table 6 highlighted the outputs of the unit root test. The finding revealed that *LnENVRtech* and *LnGLOB* are stationary at levels, showing that they reject the null hypothesis. The remaining variables are not stationary at level However, they become stationary at their first difference at a 1% significance level.

Figure 1: Study structure

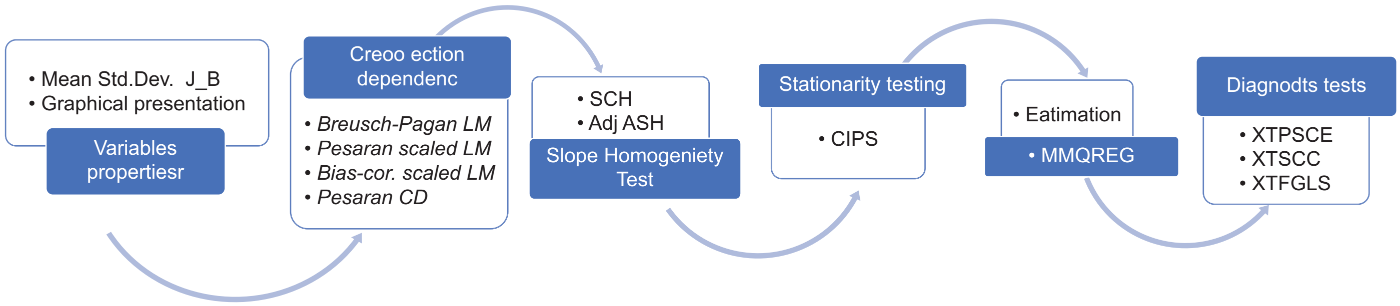


Table 3: Descriptive and normality statistics

Stat./test	*LnGHGem*	*LnGDPpc*	*LnGDPpc*^{2}	*LnGDPpc*^{3}	*LnENVRtech*	*LnSTCH*	*LnGLOB*
Mean	2.243	9.591	93.031	911.63	5.321	4.06	4.243
Max.	3.471	11.013	121.29	1335.9	9.264	4.349	4.493
Min.	0.438	6.502	42.275	274.87	−0.693	3.438	3.494
Std. Dev.	0.616	1.026	18.993	267.56	2.268	0.167	0.174
Skew.	−0.512	−0.696	−0.457	−0.264	−0.085	−0.797	−0.939
Kurt.	3.553	3.01	2.425	2.054	2.134	3.499	4.217
J-B.	25.983	37.192	22.339	22.495	14.919	53.467	96.044
Proba	0.000	0.000	0.000	0.000	0.001	0.000	0.000
Obs.	460	460	460	460	460	460	460

Source: Research finding

Table 4: Cross section tests

Variable	Breusch-Pagan LM	Pesaran scaled LM	Bias-corrected scaled LM	Pesaran CD
LnGHGem	2010.082***	93.368***	92.914***	3. 555***
P-value	(0.000)	(0.000)	(0.000)	(0.001)
LnGDPpc	3218.537***	155.361***	154.906***	52.335***
P-value	(0.000)	(0.000)	(0.000)	(0.000)
LnGDPpc^2	3215.920***	155.226***	154.772***	52.285 ***
P-value	(0.000)	(0.000)	(0.000)	(0.000)
LnGDPpc^3	3212.620***	155.057***	154.602***	52.230***
P-value	(0.000)	(0.000)	(0.000)	(0.000)
LnENVRtech	2939.98***	141.071***	140.617***	50.399***
P-value	(0.000)	(0.000)	(0.000)	(0.000)
LnSTCH	1603.396***	72.506***	72.051***	28.936***
P-value	(0.000)	(0.000)	(0.000)	(0.000)
LnGLOB	3714.849***	180.821***	180.366***	60.709***
P-value	(0.000)	(0.000)	(0.000)	(0.000)

Source: Research finding. ***Indicates the parameter significant at 0.01% significant level, *P* values are reported between parenthesis. The null hypothesis of those tests is no cross sectional dependence. The results of all tests confirm cross-section dependence, indicating that the estimators allowing cross-section dependence should be used for further investigation.

4.5. Panel Cointegration Test

Testing for the presence of cointegration among the variables is an additional requirement for panel estimation. This study employed the Pedroni panel cointegration test that considers cross-sectional dependency and heterogeneity. The null hypothesis for this test is no cointegration while the alternative hypothesis stated as all panels are cointegrated. The results in Table 7 indicate a long run relationship among the variables.

5. EMPIRICAL RESULTS

5.1. Result and Discussion of MMQREG

In estimating the suggested model in 2, we started with quantile regression which does not assume a particular parametric distribution for the response. The impacts of *LnGHGem*, *LnGDPpc*, *LnGDPpc2*, *LnGDPpc3*, *LnSTCH*, *LnGLOB*, and on GHG according to the MMQREG, are presented in Table 8 and illustrated in Figure 2. From the coefficient values of *LnGDPpc*, *LnGDPpc2*, and *LnGDPpc3*, that there is an N-shaped EKC curve. Which is in accordance with the conditions β1> 0, β2 >0 and β3 <0 and all parameters are statically significant at the 1% significant level. Therefore, with this finding, it can be said that the N curves were detected.

Table 5: Results for slope homogeneity

Test	Statistic	P-value
Δ	13.779	0.000
Δ_{Adj}	17.063	0.000

Δ represents the delta tilde, and Δ_{adj} represents the adjusted delta tilde

This result suggested that there is an advanced stage of the inverted U shaped EKC curve. This meant that the decrease in environmental degradation in the 20 top emitter countries during the period 1997 to 2019 is temporal and their future economic growth will associate with more GHG emissions. As observed from the results listed in Table 8, the effect of globalization on GHG emissions is heterogeneous under high, medium, and low quantiles. At the 75th quantile the coefficient turns to be positive but not significant. However, its effect becomes positive and statistically significant when moving to the 95th quantile.

Globalization strongly appears to promote environmental improvement in the quantiles below the 50th quantile, probably through boosted competitiveness, enhanced resource efficiencies, and greater access to low-polluted technologies (Cole, 2004; Le, 2021). The implication is that authorities of the regions should increase their effort toward globalizing their economies. This result is consistent with the findings of Zafar et al. (2019) for OECD countries, and Le et al. (2016) for a global sample. Furthermore, our result reveals positive significant influence to globalization at a 5% level in the upper quantile. This finding is in line with the finding of Lin and Wu (2022) in the case of seven emerging economies.

In addition to the above discussion, the negative and significant coefficient to the structural change indicate that a shift from pollution-intensive industrial sector economy toward the provision of services quality of the environment would improve as a result of the decrease in energy use. Accordingly, we believe that countries in the region below the 50th quantile can grasp greater environmental quality by implementing policies based on structural change results. This result is supported by Ullah et al. (2021) for Pakistan; Lenz and Fajdetić (2021) for 26 EU countries; Wu et al., 2022 for USA and India; Usman et al. (2022) for newly industrialized countries and Xu et al., 2022 for turkey.

Environment related technology tends to improve the quality of the environment, particularly in regard to realizing SDGs. Furthermore, Environment related technology boosts the quality of the environment especially in the countries with high level of GHG emission. The plausible explanations for these results could be the increasing awareness of those countries to the problem or it could be a result of the international pressure through the international organizations or bodies.

Hence, ecosystem degradation can be lessened by replacing the energy-intensive industries with environment-friendly technologies.

Table 6: Level and first difference results of CIPS unit root test

Variable	Level		First difference	
	Drift only	Drift and cons.	Drift only	Drift and cons.
LnGHGem	−1.763	−1.763	−4.324***	−4.344***
LnGDPpc	−1.817	−2.124	−3.146***	−3.430***
LnGDPpc^2	−1.793	−2.081	−3.131 ***	−3.408***
LnGDPpc^3	−1.772	−2.034	−3.114***	−3.384***
LnENVRtech	−3.384***	−3.476***	−2.766***	−4.919***
LnSTCH	−2.171**	−2.034	−3.709***	−4.054***
LnGLOB	−2.324***	−2.746**	−4.338***	−4.764***

Source: Research finding. *Indicate the parameter is significant at a 10% significant level, **indicate the parameter is significant at a 0 05% significant level and ***indicates the parameter significant at a 0.01% significant level. These findings indicate that all variables are stationary, and it is appropriate to evaluate the cointegration among the variables.

Table 7: Results of panel cointegration test

	Statistic	P-value
Modified variance ratio	−2.8732***	0.0020
Modified Phillips–Perron t	3.0250***	0.0012
Phillips–Perron t	−3.9104***	0.0000
Augmented Dickey–Fuller t	−4.2781***	0.0000

Source: Research finding. ***Indicates the parameter is significant at 0.01% significant

5.2. Robustness Checks

Since the MMQREG approach have been failed to account for the cross-sectional dependence in the data, the panel-corrected standard errors (PCSE) model.

General least square (FGLS) model and linear regression with Driscoll–Kraay standard errors (D-K) are used to test the reliability of the benchmark estimation results. Table 9 depicts the outputs of the diagnostic tests.

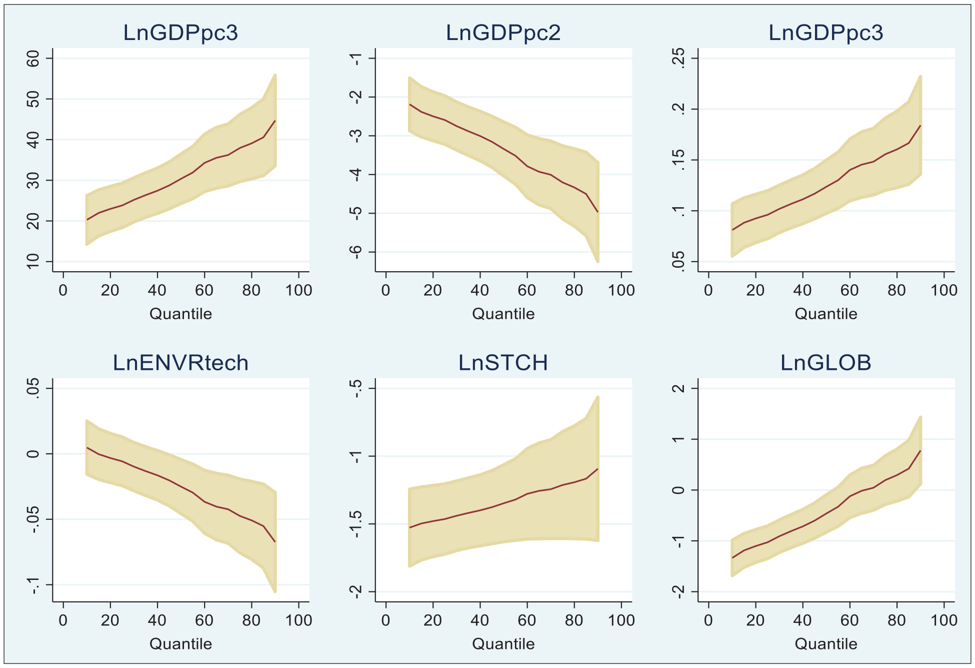
In accordance with the results obtained from the MMQREG model, the level and quadratic form of per capita income are significant and have negative signs. The cubic form of actual per capita income is significantly positive. This finding give additional support to that of the MMQREG model evidence about the existence of an N-shaped association between per capita income and GHG emissions. The N-shape result is consistent with the findings of Omay (2013) for Turkey; Baek and Pride (2014) for Japan and Spain; Onafowora and Owoye, (2014) for Brazil, China, Egypt, Mexico, Nigeria and South Africa; Sinha et al., (2017) for N-11 countries; Balsalobre-Lorente et al. (2018) in five European Union countries; Le for 16 ASEAN+6 countries; and Zhang, 2021 for China.

Table 8: MMQREG estimation results

Variable	Location	Scale	qtile_15	qtile_25	qtile_50	qtile_75	qtile_95
LnGDPpc	31.088***	7.630***	21.970***	21.119***	30.370***	37.945***	46.974***
LnGDPpc2	−3.421***	−0.869***	−2.383***	−2.354***	−3.340***	−4.203***	−5.231***
LnGDPpc3	0.1267***	0.0321***	0.0882***	0.0889***	0.1237***	0.1556**	0.1936***
LnENVRtec	−0.027*	−0.0225***	−0.0003	−0.0581***	−0.02508*	−0.0474***	−0.0741***
LnSTCH	−1.334***	0.136	−1.497***	1.0049***	−1.348***	−1.213***	−1.055***
LnGLOB	−0.399*	0.6603***	−1.188***	−0.0010	−0.460894*	0.194815	0.97631**
Constant	−85.857***	−24.55***	−56.52***	−65.53***	−83.55***	−107.9***	−137.0***

Source: Research finding

Figure 2: Quantile regression plots for method of moment quantile regression results



Source: Stata output

Table 9: Determinants of Greenhouse gas emissions: 1997–2019

Variable	PCSE	FGLS	D-K
LnGDPpc	31.088	2.484	31.088
	(4.077	(0.495)	(3.187)
LnGDPpc2	−3.421	−0.229	−3.421
	(0.464	(0.058)	(0.355)
LnGDPpc3	0.127	0.009	0.127
	(0.017)	(0.002)	(0.013)
LnENVRtech	−0.027	−0.011	−0.027
	(0.008)	(0.001)	(0.002)
LnSTCH	−1.335	−0.208	−1.335
	(0.131)	(0.012)	(0.086)
LnGLOB	−0.399	−0.274	−0.399
	(0.116)	(0.022)	(0.136)
Constant	−85.86	−6.388	(−85.86)
	(11.52)	(1.381)	(9.171)
Obs. No.	460	460	460
R^2	0.654		0.654
Groups No.	20	20	20

Source: Research finding. ***Denote statistical significance at 1% levels, FGLS: Feasible generalized least squares, D-K: Driscoll–Kraay standard errors estimations, PCSE: Panel-corrected standard errors. Standard errors are reported between parentheses

6. CONCLUSIONS AND POLICY RECOMMENDATIONS

This study aims to investigate the impacts of environment-related technology, structural change, and globalization on GHG emissions in the EKC framework for the top twenty emitter countries using panel data from 1997 to 2019. This study applies MMQREG as a baseline estimation method. The selection of the quantile regression is in order to permit the estimation of relationships across the distribution of an outcome. Since the MMQREG approach have been failed to account for the cross-sectional dependence in the data, the panel-corrected standard errors (PCSE) model, Feasible General Least Square (FGLS) model and linear regression with Driscoll–Kraay standard errors (D-K) are used to test the reliability of the benchmark estimation results. The results obtained by the four methods gave almost identical results. The most important conclusion can be drawn is the existence of an N curves describing the relationship between per capita income and environment quality. This result suggested that there is an advanced stage of the inverted U shaped EKC curve. This meant that the decrease in environmental degradation in the 20 top emitter countries during the period 1997 to 2019 is temporal and their future economic growth will associate with more GHG emissions.

Globalization strongly appears to promote environmental improvement in the quantiles below the 50th quantile, probable through boosted competitiveness, enhanced resource efficiencies and greater access to low polluted technologies.

Another important issue is the negative coefficient, and statistically significant coefficient for the structural change indicate that a shift from pollution-intensive industrial sector economy toward the provision of services quality of the environment would improve as a result of the decrease in energy use. Hence, ecosystem degradation can be lessened by replacing the energy-intensive industries with environment-friendly technologies.

Accordingly, we believe that countries in the region below the 50th quantile can grasp greater environmental quality by implementing policies based on structural change results. Based on the obtained results, the main conclusion that can draw is that economic growth might not assure the solution for the top 20 emitter countries' environmental problems. Appropriate environment related policies might play important role to emissions mitigation.

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