The Nonlinear Links Between Urbanization And CO2: Evidence From Unconditional Quantile And Threshold Regression

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The Nonlinear Links Between Urbanization and CO2: Evidence from Unconditional Quantile and Threshold Regression

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Abstract

The extant literature has provided empirical evidences about the relationship between urbanization and environment, however, a little attention has been paid to non-linear relationship among them. This study aims to measure the effects of urbanization on carbon dioxide emission using quantile and threshold regression method. To this end, the study employed threshold analysis and quantile regression method and analyzed the variation of such non-linearity for different levels of carbon dioxide using quantile regression. The results illustrate that a single threshold and two regimes exist and the threshold for urbanization is 29.56%. Across both regimes, the elasticity estimates form an inverted U-shape impact of urbanization on the carbon dioxide emission. The increase in the marginal effect of urbanization on carbon dioxide emissions up to the median level and a declining trend after this level implies that environmental quality significantly improves for emerging country.

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1. Introduction

Urbanization will be the most significant factor in transforming the world in the 21st century (UN, 2016). Rural to urban migration will add 2.3 billion people to the urban population by 2050 (UNDESA, 2018). Since 80% of the world’s carbon emission is attributed to urban areas, therefore, analyzing the environmental consequences of urbanization seems highly demanding (Salahuddin et al., 2019). As the process of urbanization takes place, more people from rural settings dependent on the agrarian economy start migrating to urban areas that are industryoriented (Zhou et al., 2019). On the one hand, developed countries have reached a high level of urbanization, but, on the other hand, developing economies are still gaining momentum for rapid urbanization (Shahbaz et al., 2016a).

The theory of urban environmental transition explains that how environmental issues are related to the development of cities at various stages (Feng et al., 2019). With the rise in industrialization, cities accumulate wealth, and this leads to a rise in pollution. With the increasing number of affluent citizens, demand for energy-intensive products also increases (Hemmati, 2006). In addition, awareness campaigns about environmental protection increase concern in citizens about environmental issues. Similarly, the continuous decrease in air quality and damage to the environment push cities to choose environmentally friendly products. Therefore, it is not clear either the wealth effect adds in or reduces pollution (Shahbaz et al., 2016a).

According to ecological modernization theory, an economy experiences various stages of its development. In the earlier stage, environmental damage becomes a serious issue; however, at a later stage, the efficiency in production, sophisticated urban planning, and transition in the economy from manufacturing to services sector reduces environmental degradation (Sadorsky, 2014). Another theory, namely urban environmental transition theory, also discusses the impact of urbanization on the environment. It finds both the positive and negative aspects of urbanization from the environmental point of view; however, the net gain or loss is ambiguous. According to compact theory, urban cities become richer, and they consume more energy-intensive products, which causes severe damage to the environment (McGranahan et al., 2001). Furthermore, urban cities are mainly related to the manufacturing sector, directly causing damage to the environment (Burton, 2000). However, this theory also highlights the positive impact of urbanization as high resource allocation for combating pollution is often found in urban cities with higher per capita income (Capello and Camagni, 2000). Besides, as the cities grow and become richer, vigilant environmental protection agencies and regulatory bodies are visible. With the rise in living standard, urbanization and use of energy efficient products goes hand in hand (Sadorsky, 2014). Compact city theory also discusses the positive side of urbanization in combating pollution. It promotes the idea of the positive effect of urbanization through economies of scale, which results in water supply, education, and sanitation on a larger level (Poumanyvong and Kaneko, 2010).

Urbanization has a huge potential of affecting economic resources (Wang et al., 2019). Interestingly, with the rise in income of urban residents, the use of environment-friendly and environment damaging products all increase rapidly (Zhu and Peng, 2012). Therefore, smart techniques and sophisticated modeling is required to capture the relationship between urbanization and environmental degradation (Wang et al., 2019).

The study has important contributions to the literature on the role of urbanization in pollution. The most important of these is the empirical methodology. In our study, it is the first time in the literature to use a different version of quantitative regression estimation. Unlike previous conditional quantitative regression estimates, our methodology allows us to further divide both structure and composition effects by the contribution of each covariate. This methodological framework is the first structure separating the general components of the decomposition of a single or group variables. This will allow us to make inferences regarding our covariates, particularly our urbanization measure that remains unchanged across the entire CO_2 distribution for the first time. Thus, by targeting the threshold level of urbanization for the first time in the literature, we can see the effect of urbanization on CO_2 symmetrically or asymmetrically. The other contribution of the study is that this threshold of urbanization level can be considered separately before and after the threshold. As mentioned earlier in this study, we use the threshold regression approach to detect the existence of any non-linear effect of urbanization on carbon emission. The most important contribution of our study to the literature is to measure the effect of urbanization on emission distributions in different regimes.

The remainder of this paper is arranged as follows; section 2 provides a fresh look into the existing literature on the nexus between urbanization, GDP, and carbon emissions, section 3 shares methodology, data, and empirical results, the final section includes conclusion and recommendations.

2. Review of literature

Although the speed and spread of urbanization globally have been very fast in the recent two decades, its role in explaining CO_2 is not yet fully identified by the previous literature (Salahuddin et al., 2019). Although the literature on the linkage between urbanization and CO_2 emissions is still growing, the findings of previous literature are still not consensual. The conflicting results are attributed to various econometric techniques used in the literature. The current strand of literature discussing the issue can be divided into conflicting groups. The first spectrum of literature supports the idea of a linear relationship, and the second supports the idea of a non-linear relationship between these two variables. For instance, Li et al. (2011) analyzed a simple linear relationship between CO_2 emission and urbanization. While on the other side, Shahbaz et al. (2016a) found a U-shaped association between urbanization and CO_2 for Malaysia.

The literature on urbanization and CO_2 relationship can be categorized as two groups in terms of unidirectional or bidirectional causality. Findings of literature dealing with the causal association between CO2 and urbanization are also mixed. Al-Mulali et al. (2015) and Khan et al. (2019) found two-way causality between CO_2 emission and urbanization in both the short and long run. In contrast, some other studies found unidirectional causality between these two indicators. Ouyang and Lin (2017) found unidirectional causality between urbanization and CO_2 emissions.

Ecological modernization theories promote the idea that it is difficult to know the prior consequences of urbanization (Salahuddin et al., 2019). However, in a recent study, Bekhet and Othman (2017) analyzed the relationship between urbanization and CO_2 emission. Using data for Malaysia during 1971-2015, the study found a long run causality between urbanization and CO_2 emission. However, the variable for urbanization and its squared term revealed an inverted u-shaped relation between urbanization and CO_2 emission. This showed that in the case of Malaysia, urbanization would be useful for the environment. On the other hand, Shahbaz et al. (2016) found a u-shaped relationship between CO_2 and urbanization for Malaysia. On the other hand, Shah et al., (2020) also found a u-shaped relation for Pakistan using Jhonson- cointegration method, while Zhan et al. (2021) found EKC for Pakistan using quantile ARDL model. Poumanyvong and Kaneko (2010) studied the impact of urban population on carbon emission and energy usage covering the period 1975-2005 for a panel of 99 countries. They found that the impact of urbanization on carbon emission and energy usage varies at various stages. In contrast, some other studies have found that regional variation may affect the impact of urbanization on CO_2 emission, for instance (Zhang and Lin, 2012) .

Al-Mulali et al. (2015) found positive effects of increasing urbanization on CO_2 emissions. A panel of 23 European countries during 1990-2013 is used in the analysis, and it is found a positive effect of urbanization in the long run. Their results of FMOLS and VECM supported the idea that foreign direct investment, urbanization, and GDP contribute to carbon emissions in the long run; however, trade openness and renewable energy reduce carbon emissions. While few other studies found a linear association between CO_2 emission and urbanization, for instance, Shah, Naqvi, and Anwar (2020) found a U-shaped relation between these two. Using time-series data for Pakistan, their study applied cointegration and VECM model. They used the EKC framework to investigate the impact of urbanization on CO_2 emission. Findings were on the side of non-linear and u-shaped relation between urbanization and CO_2. This study exploited data between 1980-2017 and found bidirectional relation between CO_2 and urbanization. Another time-series study by Bekhet and Othman (2017) analyzed the relationship between urbanization and CO_2 and found an inverse U-Shape relationship for Malaysia. The results of this study revealed a bi-directional association between urbanization and CO_2 in the long run. Similarly, Shahbaz et al. (2016) supported the same findings for Malaysia using quarterly data. This study used the STIRPAT model and VECM analysis using data from 1970 to 2011. This study supported the finding of Al-Mulali et al. (2015) that trade openness is positively associated with carbon emission. In a similar vein, Khoshnevis et al. (2019) found bidirectional causality between CO_2 emissions and urbanization. Their study used 1980-2014 data for a sample of Asian countries and applied pooled mean group estimator. For policymakers, urban planning in an environment-friendly way is a prime concern. Recent studies are focusing on urban concentration and urban agglomeration in metropolitan areas. Hashmi et al. (2020) studied urban agglomeration effect on carbon emission using newly introduced quantile-on-quantile technique. They used quarterly data of 1960-2014 and concluded that there exists a positive linkage between CO_2 emissions and urbanization.

Likewise, recent studies revealed empirical evidence about the positive association between pollution and urbanization (Ahmed et al., 2019; Ali et al., 2019). However, a mixed and insignificant association between urbanization and pollution is also reported in the previous literature. Liddle and Lung (2010) found an insignificant effect of urbanization on CO_2 emission in a sample of developed countries. Some studies reported that the linkage between environment and urbanization is positive and claimed that a rising urbanization environment tends to improve. For instance, Makido et al. (2012) argued that transport emission reduces in compact cities. Li and Lin (2015) documented that urbanization diminishes environmental pollution in a sample of high and middle-income countries. Some studies documented diverse results for the nexus between urbanization and pollution. Providing mixed results, Behera and Dash (2017) argued that income level determines the relationship between urbanization and the environment. Moreover, regional differences are reported in the previous literature supporting mixed results (Zhang et al., 2018).

Numerous studies have studied the link between CO_2 and urbanization (Shahbaz et al., 2016a; Li et al., 2018; Poumanyvong and Kaneko, 2010). The present study is novel in the sense that it applies much less explored econometric method and uses data from a panel of countries which are not yet jointly explored. The mixed nature of results provided by the previous studies on the nexus of urbanization and the environment provides much room and a need for new studies using modern econometric methods. Therefore, utilizing this gap, our study attempts to analyze the non-linear linkage between CO_2 and urbanization by employing quantile regression and a threshold model.

3. Empirical methodology and data

In our study, we argue that there exists a non-linear relationship between urban population and CO_2 emissions. To analyze the possible existence of non-linearity, this study uses the Hansen (1999). Quantile regression was proposed by Koenker and Bassett (1978) as a generalization of median regression analysis to other quantiles. There are three advantages of the quantile regression model; i) coefficients estimated are not sensitive to outliers in the dependent variable, ii) it describes the distribution of the dependent variable, iii) error terms estimated are statistically more efficient (Fitzenberger et al., 2001). The model relaxes the assumption that error terms are identically distributed and independent (Allen et al., 2013). Furthermore, Quantile regression tackles unobserved heterogeneity and heteroscedasticity, which may harm estimation accuracy (Koenker and Hallock, 2001).

However, the distributions of the CQR (Conditional Quantile Regression) approach are defined as conditional on specific covariates, which leads to an important limitation that it cannot capture dependence structures in its entirety (Dong et al., 2020). Sometimes researchers find it beyond the scope of the study to use conditional quantiles and prefer unconditional quantiles (Porter, 2015). Since the introduction of the UQR by Firpo et al. (2009), it has rapidly become popular among researchers. The advantages of quantile regression remain efficient with the UQR (Koenker and Bassett, 1978). The unconditional quantile regression model (UQR) offers the advantage that the quantiles are defined before regression. They introduced a new regression model to analyze the effect of explanatory variables on quantiles of the unconditional marginal distribution of the dependent variable. According to this method, a re-centered influence function (RIF) is regressed on unconditional quantiles of explanatory variables. Thus, variables on the right-hand side do not influence the model (Killewald and Bearak, 2014). The other feature noteworthy in the UQR is that it can include fixed effects to avoid selection bias without the need of redefining quantiles.

We first use Hansen (1999) to analyze the possible non-linear relationship between urbanization and CO2 emissions by specifying a baseline-panel regression model presented as follows

$$y_{it} = \alpha_i + \delta q_{it} + \beta_i X_{it} + e_{it} \tag{1}$$

where y_{it} denotes CO2 emissions in the country i for period t, whereas, α_i *and* e_{it} represent country-specific fixed effect and random errors. While q_{it} represents the level of urbanization for each country in the sample during time t. X_{it} represents a k dimensional vector of control variables. To work with one threshold, we transformed equation (1) into the following.

$$y_{it} = \mu_i + \beta'_1 x_{it} I(q_{it} \leq \gamma) + \beta'_2 x_{it} I(q_{it} > \gamma) + \beta_i X_{it} + e_{it} \tag{2}$$

γ is the threshold variable that demarcates the two regimes, $I(\bullet)$ is the indicator function for the two regimes with different regression slopes β'_1 and β'_2. In comparison with its linear counterpart, the following test is performed to check the validity of the threshold model using the following F statistic

$$F_1 = \frac{S_0 - S_1}{\hat{\sigma}^2} \tag{3}$$

where S_0 denotes the residual sum of squared for errors of the linear model, S_1 denotes the residual sum of squared errors of the panel threshold estimate model, and $\hat{\sigma}^2$ denotes the residual variance of the panel threshold estimation. The null hypothesis of the non-identification of γ (no threshold effect → linear relation) and its accompanying alternate hypothesis of the existence of at least one threshold given as follows.

$$H_0: \beta'_1 = \beta'_2 \text{ and } \quad H_A: \beta'_1 \neq \beta'_2$$

In case of the null hypothesis is accepted that means no threshold effect is found, the model specified in equation (2) becomes the linear model specification given in equation (1). However, it is also possible that there exists more than one threshold. Furthermore, equation (2) can be written as follows for a double threshold model.

$$y_{it} = \alpha_j + \delta_1 q_{it} I(q_{it} \leq \gamma_1) + \delta_2 q_{it} I(\gamma_1 < q_{it} \leq \gamma_2) + \delta_3 q_{it} I(q_{it} > \gamma_2) + \beta_i X_{it} + \varepsilon_{it} \tag{4}$$

In this case, our threshold estimates, $\{\gamma_1, \gamma_2 \in \mathbb{R} | \gamma_1 < \gamma_2\}$, divide our analysis into three distinct regimes that produce regime-dependent coefficients δ_1, δ_2, and δ_3, respectively. Similar to the F test for a single threshold model, we can analyze the significance of the second threshold by estimating another F statistic as given below.

$$F_2 = \frac{S_1(\hat{\gamma}) - S_2^r(\hat{\gamma})}{\hat{\sigma}} \tag{5}$$

where $S_1(\hat{\gamma})$ denotes the residual sum of squared errors from stage one threshold estimation, and $S_2^r(\hat{\gamma})$ and $\hat{\sigma}$ are the residual sum of squared errors and the residual variance from the second threshold estimation, respectively.

In the first step: model estimation for any γ, the slope coefficient can be estimated by ordinary least squares (OLS).

Namely;

$$\hat{\beta}(\gamma) = \left(X^*(\gamma)'X^*(\gamma)\right)^{-1}X^*(\gamma)'y^* \tag{6}$$

Vector of regression residues;

$$\hat{e}^*(\gamma) = y^* - X^*(\gamma)\hat{\beta}(\gamma) \tag{7}$$

and the square of the error term;

$$S_1(\gamma) = \hat{e}^*(\gamma)'\hat{e}^*(\gamma) \tag{8}$$

$$= y^{*\prime}\left(I - X^*(\gamma)'\left(X^*(\gamma)'X^*(\gamma)\right)^{-1}X^*(\gamma)'\right)y^* \tag{9}$$

The traditional OLS regression provides estimates for the conditional mean of the explanatory variables; however, quantile regression enables researchers to estimate the full range of conditional quantile (Koenker and Bassett, 1978). To estimate the impact of explanatory variables on unconditional quantiles of an outcome variable, Firpo et al. (2009) proposed a new regression method. This method proposes running a regresssion of the Recentered Influence Function (RIF) of the unconditional quantile on the explanatory variables. We followed Firpo et al. (2009) while employing the UQR.

In the second step: model estimation for any γ, the slope coefficient can be estimated by unconditional quantile regression (UQR).

The estimation methodology involves the regression of the re-centered influence function (RIF) of the dependent variable (CO2 on all repressors X). To estimate our UQRs, we have first to derive the RIF of our dependent variable (CO2). The RIF for the *th* quantile is specified as follows

$$\mathrm{RIF}(Y; q_\tau; F_Y) = q_\tau + \frac{\tau - I(Y \leq q_\tau)}{f_Y(q_\tau)} \tag{10}$$

where q_τ is the value of the outcome variable, Y, at the quantile τ . F_y is the cumulative distribution function of Y, and $f_Y(q_\tau)$ is the density of Y at q_τ . The indicator function, $(Y \leq q_\tau)$, identifies whether the value of the outcome variable, Y, for the individual is below q_τ.

The RIF enables for a linear approximation of a function that is non-linear. Using a linear regression of the new transformed outcome variable on explanatory variables, the RIF quantile regression may be used.

In our particular case, we have 15 countries for which the RIF regressions for the CO_2 emissions can be estimated using equation (7)

$$E[\, RIF(Y_{it}; q_\tau | \, X_{it})] = X_{it}\beta_{\tau,i} \tag{11}$$

where $\beta_{\tau,i}$ denotes the approximation of the marginal effects of our explanatory variables on the CO2 emissions quantile q_τ for i at $1 \leq i \leq N$.

Primarily, the model runs a regression of the newly transformed outcome variable CO_2 emissions on the explanatory variables using the RIF of the quantile marginal distribution. The RIF regression is the Unconditional Quantile Regression as the outcome variable is transformed (re-centered) into an influence function of the quantile in question.

Our study used a balanced panel data of 15 emerging countries from 1995 to 2015. These are Argentina, Bangladesh, Brazil, China, India, Indonesia, Malaysia, Mexico, Pakistan, Philippines, Russian Federation, South Africa, Thailand, Turkey, and Ukraine. The choice of data is justified due to the availability of data (Loukil, 2019; Hashemizadeh et al., 2021). The data used for the study include CO_2 emissions (metric tons per capita), urban population (% of the total population), GDP per capita (constant 2010 US$), and renewable energy consumption (% of total final energy consumption)**.** Table 1 provides a list of variables and their description. The series is sourced from World Bank's (2021) World Development Indicators.

Table 1. Data description and the statistical characteristics of factors.

Variable	Description	Mean	Std. Dev.	Min.	Max.	Obs.
$lnco_{2it}$	CO2 emissions (metric tons per capita)	0.9952	0.9982	-1.6957	2.5353	315
$lngdp_{it}$	GDP per capita (constant 2010 US$)	8.2177	0.9422	6.1303	9.5413	315
$lnren_{it}$	Renewable energy consumption (% of total final energy consumption)	2.8293	1.0147	-0.1076	4.1558	315
$lntrade_{it}$	Trade (% of GDP)	3.9846	0.5658	2.7495	5.3954	315
$lnurb_{it}$	Urban population (% of total population)	3.9632	0.3867	3.0769	4.5163	315
$lnurb_{it} \leq 3.3867$	Regime 1	3.2641	0.0950	3.0769	3.3867	26
$lnurb_{it} > 3.3867$	Regime 2	4.0260	0.3379	3.3914	4.5163	289

According to our review of the literature, it can be concluded that urbanization has a significant impact on CO2. However, the presence of the potential non-linear effect of urbanization on CO2 is ignored. Keeping in view the possibility of non-linearity, we applied a panel threshold approach. To test for a single threshold, we proceed with a test for it. Our null hypothesis is H: $\delta_1 = \delta_2$ stating that there is no existence of a threshold, and our alternate hypothesis states the existence of a single threshold. Once we can reject the null hypothesis, we can test for the existence of a higher number of thresholds. In this way, we can reach the appropriate number of thresholds in our model. To test for the existence of a single threshold, we used 1000 bootstrap in our estimation. Tables 2 and 3 show the threshold analysis. More specifically, table 2 shows single threshold existence for urbanization at 3.38, which is in log form with a confidence interval between 3.37 to 3.39. Results of the significance level of a single threshold are reported in table 3. The p-value is significant enough to reject the null hypothesis that there exists no threshold. The F-statistic is greater than the critical value, which is in favor of non-linearity and rejects the existence of a linear relationship between urbanization and carbon emission.

Table 2. Estimation of a model with a unitary threshold.

Model	Threshold	95% CI Lower	95% CI Upper
Th-1	3.3867	3.3708	3.3914

Note: CI: confidence interval. Threshold estimator (CI = 95%), with 1000 bootstrap estimates.[1]

Table 3. Test for the unitary threshold model.

Threshold	RSS	MSE	F. stat	Probability	Crit 10	Crit 5	Crit 1
Single	1.3099	0.0045	40.08	0.0670	36.9654	42.6528	56.6885

Note: CI: confidence interval; RSS: the residual sum of squares; MSE: mean squared error. Threshold estimator (CI = 95%), with 1000 bootstrap estimates.

We can now test for the existence of double and triple thresholds in the relationship between urbanization and carbon dioxide emission. The analysis performed to test for double and triple thresholds are reported in table 4 and 5. Table 4 reports three thresholds estimated for urbanization levels at 3.38, 4.04, and 4.34 in ascending order. Table 5 shows the estimates of 1000 bootstrapping to approximate the existence of double and triple thresholds. The estimates show that a single threshold is significant with a p-value of 0.06. However, double and triple thresholds are insignificant with 0.15 and 0.74 probability values. These results allow us to conclude that there exists a single threshold level in the relationship between urbanization and carbon emission.

Table 4. Estimation of models with multiple thresholds.

model	Threshold	95% CI Lower	95% CI Upper
Th-1	3.3867	3.3708	3.3914
Th-2	4.0425	4.0326	4.0495
Th-3	4.3467	4.3367	4.3505

Note: CI: confidence interval. Threshold estimator (CI ¼ 95%), with 1000 bootstrap estimates.

Table 5. Test for multiple threshold models.

Threshold	RSS	MSE	F statistic	Probability	Crit 10	Crit 5	Crit 1
Single	1.3099	0.0045	40.08	0.0670	36.9654	42.6528	56.6885
Double	1.1845	0.0040	31.14	0.1560	34.6133	39.2146	56.7336
Triple	1.1278	0.0038	14.78	0.7440	38.0283	45.7300	63.2145

Note: CI: confidence interval; RSS: the residual sum of squares; MSE: mean squared error. Threshold estimator (CI = 95%), with 1000 bootstrap estimates.

[1] The anti-log of threshold 3.3867 is equal to 29.56%, that means the threshold level is 29.56% urbanization.

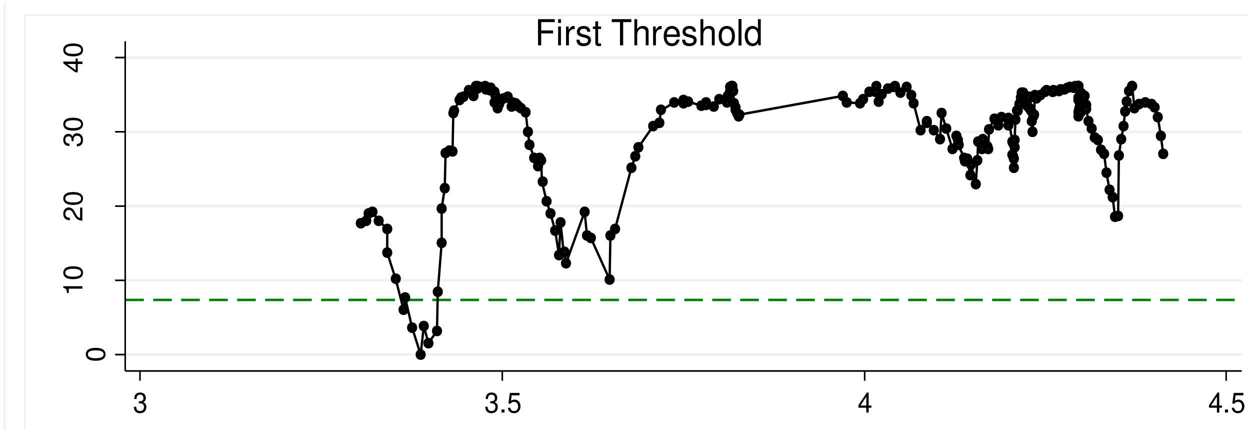


Figure 1. Threshold parameters of urbanization, the dashed green line represents 95% CI.

The graph presented in Fig. 1 also supports the results presented in Table 5 that a single threshold level exists and provides evidence for the asymmetric impact of urbanization on CO_2.

Table 6. Cross-section independence, panel unit root, and cointegration tests estimations

	CD-test value	**CIPS-stat. (level)**	**CIPS-stat. (differences)**	**Cointegration**	**Statistic**	**p value**
$lnco_{2it}$	22.99084[a]	-2.199	-4.047[a]	**Pedroni-ADF**	-9.0497[a]	0.0000
$lngper_{it}$	43.04090[a]	-1.217	-3.269[a]	**Pedroni-PP**	-5.2242[a]	0.0000
$lnren_{it}$	14.25928[a]	-2.747[b]	-4.023[a]	**Kao-ADF**	-5.208641[a]	0.0000
$lntrade_{it}$	4.145575[a]	-1.997	-3.706[a]	**Westerlund**	-1.9395[b]	0.0262
$lnurb_{it}$	35.99617[a]	-1.034	-3.191[a]			

Critical values for the CIPS test of Pesaran (2007) are − 2.56, − 2.64, and − 2.81 at 10, 5, and 1% level, respectively. [a/b/c] indicates that the variables are statistically significant at the level of 1%, 5%, and 10%, respectively.

We now move to test cross-sectional dependence among countries. Table 6 presents the results of cross-sectional dependence, unit roots, and cointegration tests for the sample countries. The CD-test proposed by Pesaran (2004) is used to test cross-sectional dependence. It has the null hypothesis that there exists cross-sectional independence among sample countries. The results of the CD-test show that there is no cross-sectional independence among countries, indicating that a shock in one may spill over to other countries. In the presence of cross-sectional dependence, a second-generation unit root test, i.e., CIPS by (Pesaran 2007), is used to test the unit root problem. CIPS estimates show that the null hypothesis of the unit root process cannot be rejected at the level for all variables except for renewable. However, at first difference, the null hypothesis can be rejected for all variables making all the series stationary. The next step we followed is to check for cointegration among the variables. We followed Pedroni-ADF, Pedroni-PP (Pedroni 2004; Pedroni 1999), Kao-ADF (Kao, 1999), and Westerlund (Westerlund, 2005) cointegration tests which are all unanimously pointing towards the presence of cointegration.

To estimation γ, the slope coefficient can be estimated by ordinary least squares (OLS) and unconditional quantile regression (UQR) and specify equation (12) as follows,

$$lnco2_{it} = \mu_i + \beta'_1 lnurb_{it} I(lnurb_{it} \leq \gamma) + \beta'_2 lnurb_{it} I(lnurb_{it} > \gamma) + \beta_3 lngper_{it} + \beta_4 lnren_{it} + \beta_5 lntrade_{it} + e_{it} \qquad (12)$$

Table 7 presents the result of a single threshold estimation for our model. The threshold variable dividing our sample into two regimes used in this analysis is urbanization, with its threshold value as γ. By this, we mean regime 1 with observations equal to or below the threshold γ, and regime 2 includes observations above the threshold γ. According to the results of the ordinary least squares (OLS) analysis, GDP per capita and renewable energy consumption are significant control variables. The impact of GDP per capita on carbon dioxide emission is positive and significant. The coefficient of renewable energy has a negative sign, showing that it decreases carbon dioxide emission.

At the next stage, to analyze the differential impact of urbanization on CO2, we re-estimated equation (8) using the UQR. To illustrate the different impacts of urbanization on the quantiles of CO2, table 7 presents the result of a quantile regression with a single threshold for our model. According to the results of the fixed effect analysis, GDP per capita and renewable energy consumption are significant control variables. The impact of GDP per capita on carbon dioxide emission is positive and significant. The coefficient of renewable energy has a negative sign showing that it decreases carbon dioxide emission. According to UQR estimations, the coefficient of trade openness is also significant in explaining CO_2; however, the fixed effect shows trade openness as insignificant.

As a result of the analysis, urbanization is the main variable of interest that significantly increases CO2 emission. Furthermore, the relationship between these two variables observed as an inverse-U shape that means non-linear. There is a slight difference between carbon dioxide and urbanization before and after this inverse-U shape. The inverse-U shape is observed when urbanization is about 3.38 (in log form or 29% in antilog). Due to a 1% increase in urbanization, there is a 0.71% increase in CO_2, but the impact is 0.75% after urbanization reaches 29%. The relatively large, though minor, impact of urbanization on CO_2 is observed after the threshold level indicates large-scale pollution after the threshold level. This might be due to scale, composition, and regulation effect in sample countries (Farhani, Chaibi, and Rault 2014).

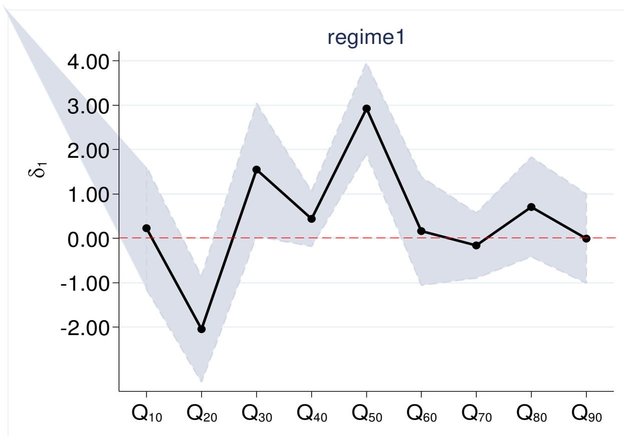
Table 7 Single-Threshold Panel Unconditional Quantile Regression and Panel Fixed Effect Estimates

$lnco2_{it} = \mu_i + \beta'_1 lnurb_{it} I(lnurb_{it} \leq \gamma) + \beta'_2 lnurb_{it} I(lnurb_{it} > \gamma) + \beta_3 lngper_{it} + \beta_4 lnren_{it} + \beta_5 lntrade_{it} + e_{it}$

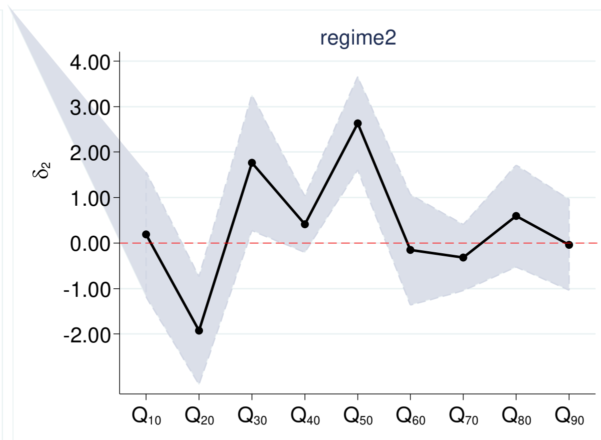
Coefficient	*10th*	*20th*	*30th*	*40th*	*50th*	*60th*	*70th*	*80th*	*90th*	OLS
$\beta_1 \leq 3.3867$	0.2293	-2.0454[a]	1.5457[b]	0. 4373	2.9242[a]	0.1634	-0.1639	0.7059	-0.0058	0.7136[a]
	(0.33)	(-3.37)	(2.02)	(1.38)	(5.56)	(0.26)	(-0.44)	(1.23)	(-0.01)	(9.09)
$\beta_2 > 3.3867$	0. 1913	-1.9256[a]	1.7656[b]	0. 4129	2.6345[a]	-0.1493	-0.3207	0.5948	-0.0366	0.7596[a]
	(0.27)	(-3.19)	(2.32)	(1.31)	(5.04)	(-0.24)	(-0.87)	(1.04)	(-0.07)	(9.73)
β_3	0. 2154	0.8725[a]	0.1475	0. 0131	0.4964[a]	1.1274[a]	0.6653[a]	0.3034	0.1009	0.2606[a]

	(0.86)	(4.04)	(0.54)	(0.12)	(2.66)	(5.11)	(5.03)	(1.49)	(0.56)	(9.33)
β_4	-0. 0638	-0.0927	0.0399	0.0752	-0.3047 [b]	-0.6927 [a]	-0.7263 [a]	-1.4899 [a]	-0.0308	-0.3223 [a]
	(-0.32)	(-0.54)	(0.19)	(0.84)	(-2.05)	(-3.95)	(-6.91)	(-9.21)	(-0.21)	(-14.54)
β_5	-0.0653	0.3330 [c]	-0.7070 [a]	0.0511	0.3604 [b]	0.7079 [a]	0.1000	-0.7084 [a]	0.1132	-0.0175
	(-0.31)	(1.82)	(-3.08)	(0.54)	(2.28)	(3.79)	(0.89)	(-4.11)	(0.74)	(-0.74)

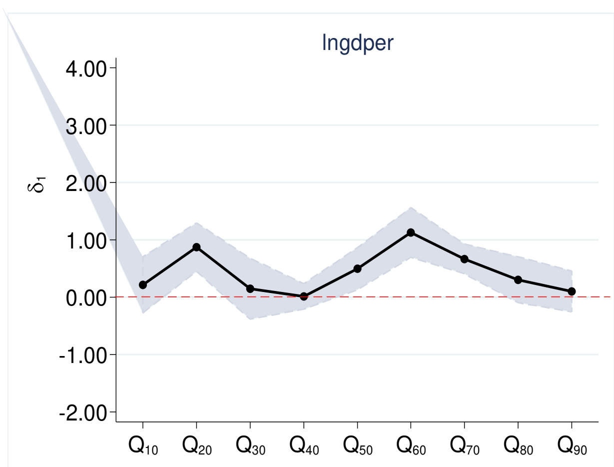
Notes: [a]/[b]/[c] indicates that the variables are statistically significant at the level of 1%, 5%, and 10%, respectively. Parenthesis shows the t-statistics.



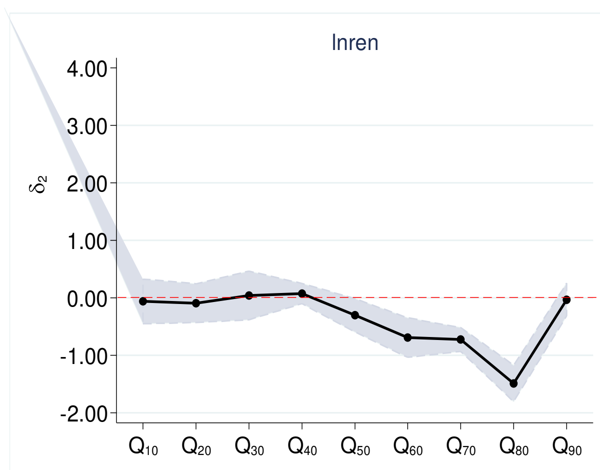
The effect of $lnurb_{it} \leq \gamma$ on CO2 emissions



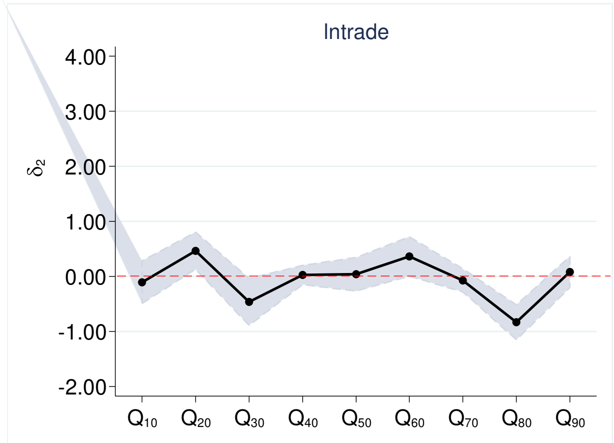
The effect of $lnurb_{it} > \gamma$ on CO2 emissions



The effect of gdp on CO2 emission



The effect of renewable on CO2 emissions



The effect of trade on CO2 emissions

Figure 2. Dynamics of panel quantile regression coefficients. Note the grey area represents the 95% confidence interval for quantile regression estimators.

Table 7 also presents the results of the quantile regression model for nine different quantiles. It is interesting to note that, unlike the fixed effect estimation, the impact of urbanization on CO_2 is both positive and negative. At some levels of CO_2, the relationship is insignificant. Results are both mixed as positive and negative at 60th quantile, indicating the importance of quantile-based analysis. The magnitude of the impact of urbanization on CO_2 is mixed at various quantile levels. Thus, after a certain level of urbanization, its role in pollution becomes more vital.

Based on the charts presented in Figure 2, we can see that at various quantiles of urbanization, the impact of urbanization on CO_2 is different. Using quantile regressions, we find the elasticity estimates form an inverted U-shape across both regime impact of urbanization on the carbon dioxide emissions distribution. More specifically, the results of the ordinary least squares (OLS) and the quantile regression (UQR) are consistent below the median level, whereas the results are mixed above the median level.

Our results do not completely match or contradict with the previous literature. Fan et al. (2006) found a negative effect of urbanization on CO_2 for high-income countries but insignificant for middle and low-income countries. Ali et al. (2017) also found a negative impact of urbanization on CO2 for Singapore. Sadorsky (2014) found an insignificant impact of urbanization on CO_2. Similar to our results, Ahmed et al. (2019) and Khan et al. (2019) found a positive impact of urbanization on CO2. However, Shahbaz et al. (2016) for Malaysia found a U-shaped relationship, and Bekhet and Othman (2017) for Malaysia; He et al. (2017) for China and Ahmed et al. (2019) for Indonesia found inverted U-shaped relations. Studies using the quantile regression method found a mixed impact of urbanization on CO2 H. Zhu et al. (2018) found a negative impact, while Lin and Benjamin (2017) found a positive effect.

To test the robustness of our results, we re-estimated our model with an alternative specification, following You et al. (2015). Salman et al. (2019) found that exports increase CO_2 emissions. Other studies discussed the pollution halo effect Sarkodie and Strezov (2019) and Liu et al. (2018) and the pollution haven hypothesis (Zhang et al., 2019). The effect of trade on CO_2 has scale, composition, and regulation effect (Farhani et al., 2014). In the alternative specification of the model, we dropped trade openness as a covariate. The results are reported in Table 8, which shows that impact of the threshold variable at various levels of CO_2 is the same. Therefore, this robustness check largely supports our results.

Table 8: Robustness check: excluding trade openness

$lnco2_{it} = \mu_i + \beta'_1 lnurb_{it} I(lnurb_{it} \le \gamma) + \beta'_2 lnurb_{it} I(lnurb_{it} > \gamma) + \beta_3 lngper_{it} + \beta_4 lnren_{it} + e_{it}$

Coefficient	*10th*	*20th*	*30th*	*40th*	*50th*	*60th*	*70th*	*80th*	*90th*	**OLS**
$\beta_1 \le 3.3867$	0.1929	-1.8602 ^{a}	1.1524	0.4658	3.1247 ^{a}	0.5572	-0.1083	0.3119	0.0571	0.6995 ^{a}
	(0.28)	(-3.09)	(1.51)	(1.49)	(5.99)	(0.89)	(-0.30)	(0.54)	(0.11)	(9.10)
$\beta_2 > 3.3867$	0.1475	-1.7022 ^{a}	1.2913 ^{c}	0.4472	2.8763 ^{a}	0.3255	-0.2536	0.1195	0.0393	0.7455 ^{a}
	(0.22)	(-2.87)	(1.71)	(1.45)	(5.58)	(0.53)	(-0.70)	(0.21)	(0.08)	(9.82)
β_3	0.2223	0.8371 ^{a}	0.2226	0.0076	0.4582 ^{a}	1.0523 ^{a}	0.6547 ^{a}	0.3786 ^{c}	0.0889	0.2623 ^{a}
	(0.90)	(3.88)	(0.81)	(0.07)	(2.45)	(4.68)	(4.97)	(1.82)	(0.49)	(9.51)
β_4	-0.0624	-0.0996	0.0545	0.0741	-0.3122 ^{b}	-0.7073 ^{a}	-0.7283 ^{a}	-1.4753 ^{a}	-0.0331	-0.3206 ^{a}
	(-0.32)	(-0.58)	(0.25)	(0.83)	(-2.09)	(-3.94)	(-6.93)	(-8.89)	(-0.23)	(-14.57)

Notes: $^{a}/^{b}/^{c}$ indicates that the variables are statistically significant at the level of 1%, 5%, and 10%, respectively. Parenthesis shows the t-statistics.

4. Conclusion

The main contribution of this study is to recheck for any possible non-linear relationship between carbon emission and urbanization. Additionally, we analyzed the variation of such non-linearity for different levels of CO_2. Using quantile regressions, we find that across both regimes the elasticity estimates form an inverted U-shape impact of urbanization on the carbon dioxide emissions distribution. More specifically, the results of the ordinary least squares (OLS) and the quantile regression (UQR) are consistent below the median level, whereas the results are mixed above the median level.

Besides, the threshold analysis shows that there exists a single threshold which is 29.37 % of the urbanization level. OLS results show that there is a marginal effect of threshold variable; besides, results of quantile regression show mixed behavior in two regimes. We concluded based on threshold methodology that urbanization contributes toward carbon emission relatively strongly up to a certain level. We found a strong impact of urbanization on carbon dioxide emission, which is irrespective of the level of urbanization and CO_2 emission, we conclude that urbanization is a strong driver of CO_2. The UQR analysis show that the impact of urbanization on CO_2 emissions vary with the level of CO_2.

The results of the OLS estimation elasticity and the UQR flexibility results decrease the elasticity effect of urbanization on CO_2 emission distributions for developing countries after the median differentiation urbanization implies that environmental quality significantly improves for emerging country. Hence, policymakers in these countries may pay special attention to these findings while making effective strategies to cope up with environmental challenges and urbanization. Policy implication from this paper is that while allocation of resource to various sectors of economy, attention should be paid to environment-urbanization linkage keeping in view the level of urbanization in the country. Future studies may replicate the methodology and model on a different sample and validate the relationship. There is still much work to do in future on this topic, for instance, how institutions and other macro variable mitigate the relationship between CO_2 and urbanization.

Future research guidelines

As for relevant research in the future, some new research areas, such the impacts of urban agglomeration on the environment, deserve further research. It will be interesting to explore the impact with more larger data set covering maximum countries. Our results are highly sensitive to sample countries, thus, their validity is only for aggregate. Future research may focus on identifying specific threshold level of urbanization for each country.

A. Appendix

Table 9 Sample emerging countries

Argentina	Pakistan
Bangladesh	Philippines
Brazil	Russian Federation
China	South Africa
India	Thailand
Indonesia	Turkey
Malaysia	Ukraine
Mexico	

Table 10 Correlation Matrix

Variables	lnco2	lngdper	lnren	lntrade	lnurban
lnco2	1				
lngdper	0.7703[a]	1			
lnren	-0.7874[a]	-0.4781[a]	1		
lntrade	0.4044[a]	0.1722[a]	-0.5079[a]	1	
lnurban	0.7142[a]	0.884[a]	-0.615[a]	0.0844	1

Notes: [a]/[b]/[c] indicates that the variables are statistically significant at the level of 1%, 5%, and 10%, respectively.

Table 11 Description of quantiles for all the variables in our model.

Variables	***10th***	***25th***	***50th***	***75th***	***90th***	***Skewness***	***Kurtosis***
$lnco_{2it}$	-0. 2141	0.1736	1.25162	1.78786	2.16822	-0.6010	2.6883
$lngdp_{it}$	6.7471	7.4622	8.50941	9.05847	9.24821	-0.5237	1.9705
$lnren_{it}$	1.2767	2.2848	3.00827	3.7339	3.89414	-0.8531	2.9855

$lntrade_{it}$	3.2905	3.5872	3.92626	4.26881	4.82703	0.4412	2.8195
$lnurb_{it}$	3.4164	3.5856	4.06452	4.29554	4.41684	-0.4162	1.9286
$lnurb_{it} \leq 3.3867$	3.1107	3.18205	3.292955	3.34063	3.36619	-0.6425	2.0956
$lnurb_{it} > 3.3867$	3.4929	3.78118	4.13761	4.29833	4.42782	-0.4015	1.8505

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Declarations

Ethics approval and consent to participate

No human data is involved in this research.

Consent for publication

It is not applicable to this study, as there is no human data involved in it.

Availability of data and materials

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Competing interests

The authors declare that they have no competing interests

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Authors' contributions

All the authors contributed equally to this research. MK analyzed and interpreted the threshold and quantile regression estimation to obtain the potential effects of urbanization and other variables on CO2 emissions. Ashar Awan performed preliminary analyses for the panel data and prepared the methodologies of threshold and quantile regression models in the methodology section. AT expanded the discussion section by comparing our findings with the findings of other works in the literature. Alper Aslan reviewed the literature and wrote the introduction section and underlined the motivation of the manuscript. All authors read and approved the final manuscript.

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Authors' agreement

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