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Nexus between Technological Innovation, Renewable Energy, and Human Capital on the Environmental Sustainability in Emerging Asian Economies: A Panel Quantile Regression Approach

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Abstract: The goal of this study was to examine the interlinkage of renewable energy, technology innovation, human capital, and governance on environment quality by using a panel quantile regression in Asian emerging economies over the period of 1990–2019. The results indicated that higher economic growth, population density, technological innovation in renewable energy, and exploitation of natural resources have significantly raised CO_2 emissions in emerging Asia. Furthermore, larger capital, more use of renewable energy, green technology, and human capital development can improve environmental sustainability in Asia. As for governances, proxied by corruption rates, no evidence indicated that it has resulted in more damage, unlike earlier studies have suggested. The findings indicated that the three channels exposed in the Kuznets hypothesis can serve as a reference for proposals for environmental policies (scale of consumption, energy composition, and choice of technologies). There are opportunities to reduce CO_2 emissions through investments in human development, investing in new technologies to increase efficiency in energy (generation and consumption), increasing working capital (GCF), and migrating to more environmentally friendly energy. The negative link between carbon dioxide emissions and economic growth, increases in population density, and exploitation of natural resources can compromise the achievement of sustainable environmental goals.

Keywords: technological innovation; panel quantile regression; environmental sustainability; CO_2 emissions; renewable energy; emerging Asian economies

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1. Introduction

The increase in carbon dioxide (CO_2) emissions has prompted extensive research, especially due to its impact on the environment. The general belief is that excessive emissions of CO_2 deteriorate life quality and environmental sustainability. Studies have also shown how economic growth prompts more CO_2 emissions and contributes to environmental degradation [1,2]. Other factors identified in previous research include energy consumption [3], population growth [4], capital accumulation [5], and corruption [6]. On the other side of the equation, improvements in human resources [7], technological innovation [3], and renewable energies [8] can reduce CO_2 and support environmental sustainability.

In the last three decades, rapid economic growth in emerging economies has led to increased emissions in Asia. Evidence suggests a negative effect of economic growth on environmental sustainability in Brazil, Russia, India, China, and South Africa (BRICS) countries [3,5]. The surge in emissions in China [9], South Asia [10], and other large emerging economies was linked to high energy consumption as noted in Adebayo et al. [11]. Other factors affecting environmental quality include population growth, industrial activity, and poor governance [12].

The use of innovative technologies and renewable energies, the rate of corruption, and the improvement of human capital, are emerging issues in Asian economics, but research has yet to uncover their impacts on environmental sustainability. Research in this area is fundamental in growing economies such as China, South Korea, India, Pakistan, Indonesia, Malaysia, and Thailand, as they shape the development model in the region as noted by Danish et al. [13]. Besides, they have substantial natural resource reserves that will significantly impact the environment if not appropriately managed as pointed out for cases on emerging countries [5,14].

Carbon dioxide emissions in emerging Asian countries increased by nearly 400% from 1990 to 2019, likely driven by the growing economic activities, population increase, and higher energy consumption. According to the International Energy Agency (IEA, Paris, France), the total renewable energy consumption in Asia (excluding China) increased from 85 GWh in 1990 to 63,119 GWh in 2019. Altogether there has been a shift towards renewable sources, although many countries, including China, Indonesia, Pakistan, Thailand, Malaysia, and India, continue relying on non-renewable sources. These countries are also lagging in technological innovation, alternative energies, good governance, and human resource development, as pointed out by Balsalobre-Lorente et al. [15], even when these factors are critical in supporting environmental sustainability (e.g., Brazil in [11]).

This study investigated the nexus between CO_2 emissions and technological innovation, renewable energy use, and human capital development in Asian emerging countries—China, South Korea, India, Pakistan, Indonesia, Thailand, Malaysia, and the Philippines—from 1990 to 2019. The findings were expected to extend the literature focusing on the link between the environment and economic growth, population, corruption, and use of natural resources. We used a panel quantile regression approach to identify the variables' heterogeneous structure and capture the market structure's differences of the sample data. As demonstrated by Allard et al. [16], the quantile approach is a powerful tool to evaluate the environmental Kuznets hypothesis in a panel context. Unlike systems based on mean values (e.g., pooled OLS, FEM, or REM approaches), the quantile method estimates different points on the conditional distribution of the chosen dependent variable (see [17,18]).

The current study offered the following contributions. First, we applied a panel quantile regression that allows for an estimation of the conditional distribution, as opposed to conditional mean in OLS-based approaches. This allowed us to examine the link across quantiles, and hence, the CO_2 emissions' rates across countries. Second, we investigated the countries in Asia with a great demand for energy and growing innovation, renewable energy use, human development, and good governance as pointed out by Zafar el al. [19]. Third, we employed variables that drive emissions (GDP, energy consumption, population, and corruption) and those that reduce emissions (innovation, renewable energies, human development, and capital growth). Fourth, we tested Kuznets hypothesis, which states that economic expansion propels emissions in three channels (Halliru et al. [7]): by scale, i.e., consumption of energy associated with larger growth; by composition, i.e., choice of energies; and by technique, i.e., technology choices. The proposed model aimed to capture all three channels, which has not been attempted in past research. Additionally, the region has been engaging in sustainable practices in the last decades, so an assessment of whether the development and policy have been supportive is needed (see [15,18,19]).

2. Literature Review

Previous research examined the drivers of carbon emissions from an economic perspective, mainly under the Kuznets hypothesis, which identifies how economic activities impact the environment in three channels. The first is through the scale of economic growth, which is synonymous with greater energy demand. The second is the composition of renewable and non-renewable energy adoptions. There has been plenty of research in this area of study in advanced and emerging countries, e.g., Adebayo et al. [11] for Brazil, Halliru et al. [7] for West African states, and Yao et al. [8] for major developing countries. The general assumption of the Kuznets hypothesis is that income growth drives energy demand, hence increasing CO_2 emissions at a rapid rate until it reaches a certain threshold. The threshold that leads to recovery varies depending on different factors. Azam and Khan's [6] study in Southeast Asia confirmed the hypothesis applying ordinary least squares (OLS). Other studies using augmented mean group (AMG) [3] and bootstrap ARDL [20] in BRICS, and panel quantile regression in Africa [7], revealed that capital inflows (domestic or foreign) have driven environmental degradation forward.

In emerging Asian countries, CO_2 emissions have increased due to the rising demand for energy and the intensive use of non-sustainable energy resources as noted by Hanif et al. [21] who applied an ARDL approach. The adoption of greener technologies has lowered the emissions rate in emerging countries as confirmed by Adams and Nsiah [22] using a GMM model, although not as low as in advanced countries. A shift towards more renewable sources could also decrease CO_2 emissions as supported in cases for emerging countries [10,11], G7 nations [23], and large economies including India and China [24,25]. However, this was not the case in other Asian countries such as India, Pakistan, and Bangladesh [26]. This begs the question as to whether adopting renewable technologies at a larger scale can offer a positive impact on environmental sustainability in emerging Asian countries.

Meanwhile, innovative technology has proven to be effective in improving the environment in many countries and economic regions, including Brazil [11], APEC [19], the G7 [23], and BRICS [3]. This is because innovative technologies can make power generation and energy use more efficient, which is good for the environment as found by Yao et al. [5] for major developing countries using a GMM model. Innovative technologies can also regulate the exploration of natural resources and monitor governance, leading to better environmental conditions.

Good governance and human resource development also reduce CO_2 emissions as supported by Zafar et al. [19] for Asia Pacific countries. Corruption, on the other hand, may hinder sustainability program delivery. In 16 OECD countries, a higher corruption perception index was found to be unfavorable to achieving reduction targets of CO_2 emissions [15]. Corruption may also lower the impacts of innovative programs and other policies to improve the environment [8,12]. In Southeast Asia, Azam and Khan [6] found a significant impact of corruption on the effort to reduce CO_2 in Malaysia, but not in Thailand and Indonesia. Applying quantile regression, Luqman et al. [27] found that anticorruption policies and human capital improvements supported environmental sustainability in Pakistan. Studies covering China, India, and other emerging countries tended to support that improvements in governance can moderate energy consumption [2,5,10].

In terms of wealth in natural resources, using an ARDL approach, Tufail et al. [28] found that developed countries with rich natural resources but poor governance emit more CO_2. They also believed that decentralization could improve the situation because local authorities have more power to address environmental challenges more effectively. As for developing countries, evidence suggested that abundant natural resources and poor governance are likely to harm the environment [12,14,29]. Therefore, controlling corruption is necessary to prevent the exploitation of natural resources and reduce the carbon footprint [5].

Considering the mixed results found in the literature, this study provided new evidence on the three channels described in the Kuznets hypothesis with respect to the means by which economic development could impact the environment. The variables chosen in this study attempted to provide evidence on each of the three channels: scale was approximated by GDP and population density; the composition channel was captured through the consumption of renewable and non-renewable energy; the choice of energies and technique channel was approximated with gross capital formation and patents in renewable and non-renewable energies. Finally, corruption control and natural resources were two variables that could alter the environmental curve, either by adding or diminishing the effects. As described, there is no absolute evidence on the impact of the proposed variables in the context of emerging Asian countries.

3. Materials and Methods

This study used cross-sectional data from eight countries: China, India, Indonesia, Korea, Malaysia, Pakistan, the Philippines, and Thailand, from 1990 to 2019. Table 1 describes the variables employed in this study and the corresponding data sources. Panel quantile regression—initially introduced by Koenker and Bassett [30]—was used in the estimations following earlier studies [7,31]. As noted by Zhu et al. [18], by using fixed effects panel quantile regressions, we could estimate how the variables modulated CO_2 emissions 'throughout a conditional distribution', including in countries with high and low levels of emissions.

Table 1. The variables and data Sources.

Variables	Description	Source
EQ	Carbon dioxide (CO_2) emissions in Kt units as the environment's quality	EIA
COR	Control of corruption	WGI
GCF	Gross capital formation (percent of GDP)	WDI
HDI	Human development index	UNDP
GDP	Economic growth	WDI
TI_R	Technology patent application for renewable energy	WDI
TI_NR	Technology patent application for non-renewable energy	WDI
RE	Total of renewable energy consumption	EIA
NRE	Non-renewable energy to primary energy	EIA
NR	Total natural resources rent (percent of GDP)	WDI
PO	Population density	WDI

Note: Energy Information Administration (EIA), World Governance Indicator (WGI), World Development Indicator (WDI), United Nations Development Programme (UNDP).

According to De Silva et al. [32] and Salman et al. [33], OLS regression assumptions such as the random disturbance is zero-mean and identically distributed, with error terms usually identically distributed. This may not occur in real life, as economic and social indicators may be distributed differently in a dataset. Other OLS assumptions, namely, heteroscedasticity, unbiased estimation, and minimum variance, are also unrealistic [34]. Therefore, panel quantile regression is a more reasonable approach as it can accommodate distribution differences [33].

Panel quantile regression is based on the regression of an independent variable with the conditional distribution of the dependent variable, estimated to produce a regression model for all quantiles [34]. It is not limited by classical distribution assumptions, which are unlikely to be met [35] and can better capture the tail characteristics of a variable distribution [34].

To analyze the effect of an independent variable on the dependent variable, the following model was adopted:

$$\begin{aligned} EQ_{CO2_{it}}(\pi_k/\alpha_i,\ x_{it}) &= \alpha_i + \beta_1 COR_{it} + \beta_2 Ln GCF_{it} + \beta_3 Ln HDI_{it} + \beta_4 Ln GDP_{it} + \beta_5 Ln TI_{Rit} + \beta_6 Ln TI_{NRit} + \beta_7 Ln RE_{it} \\ &+ \beta_8 Ln NRE_{it} + \beta_9 NR_{it} + \beta_{10} PO_{it} \end{aligned} \quad (1)$$

where i and t are country and year (fixed effects), π_k represents the quantile number, *Ln* is the natural logarithm, and EQ is the dependent variable (CO_2). The independent variables are control of corruption (COR) as a proxy of good governance, gross capital formation (GCF) as a proxy of physical capital, human development index (HDI) as a proxy of human capital, gross domestic product (GDP) as a measure of economic growth, technology patent application for renewable energy (TI_R) as a measure of innovation technology, technology patent application for non-renewable energy (TI_NR), total renewable energy consumption (RE), non-renewable energy to primary energy (NRE), total natural resources rent (NR), and population density (PO). See Table 1 for details.

The control of corruption index is compiled by the World Bank under the World Governance Indicators (WGI). Control of corruption is one of the six indices to generate an indicator of governance. The WGI defines control of corruption as "perceptions of the extent to which public power is exercised for private gain, including both petty and grand forms of corruption, as well as "capture" of the state by elites and private interests". The index of control of corruption ranged from a weak point of –2.5 to a strong point of 2.5. A survey of experts on the perception of control of corruption is applied to obtain these indices.

As the statistical distribution of the data often follows a non-equal variation, the location of the conditional distribution of the data is therefore unequal. In a quantile regression, the conditional distribution is spread across different quantiles, where a mean is represented by the 50th quantile [36]. As such, quantile regressions are more suitable to evaluate samples in the presence of outliers than any estimation techniques based on mean conditional distribution. A quantile approach allows capturing the different slopes for the other set of quantiles.

The initial hypothesis of this study was that increasing GDP would increase CO_2 emissions as energy demand also rises; by contrast, more use of renewable energy would lead to a decrease in CO_2 emissions. The use of technology would also reduce emissions as production would be more efficient. As for good governance (proxied by low corruption level) and human capital improvement (HDI), we hypothesized that both would reduce emissions. Finally, greater non-renewable energy use, population density, and abundance of natural resources were likely to increase emissions. As for gross capital formation, the result could be either positive or negative, depending on whether it was directed for more efficient technology or the other way round.

Thus, the panel quantile regression model was used to examine the link among the variables at different points of the distribution (across quantiles). The standard regression model represents the association between an explanatory variable (x) and the dependent variable (y) following E ($y \mid x$). By contrast, the quantile regression approach constricts the relationship based on the conditional distribution on the variable y [37]. Considering that not all the variables follow an equal statistical distribution, the relationship among variables may be subject to the conditional distribution function of the dependent variable. The quantile regression proposed by Koenker and Bassett [30], thus, estimates the conditional distribution of output variables [17]. A standard quantile regression can be presented as

$$y_i = x' \beta_q + e_i, \tag{2}$$

where β_q indicates the vector(s) of parameters to be estimated pertaining to the percentile quantile qth [38]. The conventional least squares regression estimates the conditional expectation of the response variable by minimizing the sum of squares of the unobserved factors, or error, $e_i \left(\sum_i e_i^2 \right)$. The quantile regression estimates the conditional median or other quantiles of the response variable by targeting the minimization of the objective function:

$$Q\left(\beta_q\right) = \sum_{i:y_i \geq x_i' \beta}^{N} q \left| y_i - x_i' \beta_q \right| + \sum_{i:y_i < x_j' \beta}^{N} (1-q) \left| y_i - x_i' \beta_q \right|, \tag{3}$$

for $0 < q < 1$. As suggested in the literature [38], the quantile approach of Powell [39] was used to validate results. The panel quantile regression of Powell follows a non-additive regression model at various distribution points (percentiles) of CO_2 release. This model was suggested by Powell [39] and proven to offer robust inference when examining long-run paths of CO_2 emission [38].

The procedure to compute the parameters in the model proposed in Equation (1) is as follows: the first step taken before estimating the panel quantile regression is to test the cross-sectional dependence on the panel data in order to determine the homogeneity of the data and determine if the univariate time series possess a unit root. The rejection of the null hypothesis in the cross-sectional dependence test allows for the heterogeneity panel estimation condition (Halliru et al. [7]). Furthermore, it is necessary to check the stationarity of the variables to avoid spurious regressions. A cointegration test is then carried out to see if there is a long-term relationship between the variables. The results of the panel integration test using Johansen Fisher depend on the lag order of the VAR system fitted to all variables (Zhu et al. [18]).

After the aforementioned tests were carried out and the proper hypothesis was tested, we used a quantile regression panel model with fixed effects in order to predict the effect of conditional heterogeneous covariance of the dependent variable so as to control for individual heterogeneity that is not observed [37]. The fixed effect panel quantile regression model is as follows:

$$Qy_{it}(\tau_k|\alpha_i, x_{it}) = \alpha_i + x_{it}^{T}\beta(\tau_k) \quad (4)$$

where $i = 1, \ldots, N$; $t = 1, \ldots, T$. In this formula, α_i has a pure location shift effect on the conditional quantile of the response. The effect of the x_{it} covariate may depend on the τ quantile. i is individual and t is time. N is the number of observations on individual i. T is the number of observations at time t.

The unique characteristic of this method is the existence of a penalty term in minimizing computational problems in estimating the mass of parameters specifically (Chen & Lei [40]; Zhu et al. [18]). The parameter estimation is calculated as follows:

$$\min_{(\alpha,\beta)} \sum_{k=1}^{K}\sum_{t=1}^{T}\sum_{i=1}^{N} w_k \rho\tau_k\left(y_{it} - \alpha_i - x_{it}^{T}\beta(\tau_k)\right) + \lambda\sum_{i}^{N}|\alpha_i| = 1, \ldots, N;\ t = 1, \ldots, T \quad (5)$$

where K is the quantile index, x is the explanatory variable matrix, $\rho\tau_k$ is the quantile loss function, w_k is the relative weight assigned to the quantile $(w_k = 1/K)$ which controls the contribution of the kth quantile to the fixed effect estimate, and λ is a tuning parameter that reduces individual effects to zero to improve estimation performance $(\lambda = 1)$.

4. Results

4.1. Empirical Results

Table 2 shows the original data's descriptive statistics before transformation using natural logarithms. Prior to the estimations, the Jarque–Bera test was applied as a goodness-of-fit test to validate that the data had the skewness and kurtosis following a normal distribution. As indicated in Table 2, only the HDI variable was not normally distributed, indicated by the insignificant result of the Jarque–Bera test.

Table 2. Descriptive statistics.

Variables	Mean	Median	Maximum	Minimum	Std. Dev.	Skewness	Kurtosis	Jarque–Bera
EQ	1,125,592.00	254,777.70	10,291,927.00	41,763.46	2,227,455.00	2.994	11.385	1061.747 ***
COR	−0.39	−0.34	0.45	−1.59	0.46	−0.7	2.73	20.13 ***
GCF	28.79	27.62	46.66	14.12	8.38	0.26	2.06	11.60 ***
HDI	0.65	0.65	0.92	0.402	0.12	0.08	2.49	2.93
GDP	1.04×10^{12}	3.97×10^{11}	1.15×10^{13}	7.93×10^{10}	1.84×10^{12}	3.623	16.925	2464.4 ***
TI_R	54,932.4	856	1,393,815	0	193,235.3	5.175	30.82	8817.8 ***
TI_NR	17,188.89	4970.5	157,093	0	29,063.53	2.81	11.03	961.2 ***
RE	28.32	30.37	58.65	0.44	18.06	−0.096	1.73	16.44 ***
NRE	3.69	2.24	18.49	0.39	4.61	2.05	5.83	248.1 ***
NR	3.78	2.27	25.86	0	4.11	1.88	7.55	348.9 ***
PO	3.78×10^{8}	1.08×10^{8}	1.40×10^{9}	1.80×10^{7}	4.90×10^{8}	1.167	2.527	56.8 ***

Note: *** significant at 1% level of significance. Carbon dioxide CO_2 (EQ); Control of corruption (COR); Gross capital formation (GCF); Human development index (HDI); Economic growth (GDP); Technology for renewable energy (TI_R); Technology for non-renewable energy (TI_NR); Renewable energy consumption (RE); Non-renewable energy to primary energy (NRE); Total natural resources rent (NR); Population density (PO).

The results of the cross-sectional dependence tests using the Pesaran CD test [41], the bias-correlated scaled LM, the Pesaran-scaled LM, and the Breusch–Pagan LM are shown in Table 3. There was sufficient cross-sectional dependence in the eight countries involved in this study. Using Pesaran and Yamagata [42], we tested the homogeneity conditions. Apergis et al. [31] stated that the cross-dependence test is crucial before applying the unit root test. The null hypothesis was that there was no sufficient cross-sectional dependence of the variables used in this study.

Table 3. Cross-dependency test results.

Variables	Pesaran CD Test		Bias-Corrected Scaled LM		Pesaran Scaled LM		Breusch–Pagan LM	
	Statistic	*p*-Value	Statistic	*p*-Value	Statistic	*p*-Value	Statistic	*p*-Value
*Ln*EQ	27.45 ***	0.000	96.90 ***	0.000	97.04 ***	0.000	754.2 ***	0.000
COR	14.24 ***	0.000	62.91 ***	0.000	63.05 ***	0.000	499.8 ***	0.000
*Ln*GCF	3.99 ***	0.000	22.11 ***	0.000	22.24 ***	0.000	194.5 ***	0.0001
*Ln*HDI	28.73 ***	0.000	106.4 ***	0.000	106.5 ***	0.000	825.2 ***	0.000
*Ln*GDP	28.60 ***	0.000	105.5 ***	0.000	105.6 ***	0.000	818.2 ***	0.000
*Ln*TI_R	24.22 ***	0.000	75.98 ***	0.000	76.12 ***	0.000	597.6 ***	0.000
*Ln*TI_NR	14.67 ***	0.000	32.37 ***	0.000	32.51 ***	0.000	271.3 ***	0.000
*Ln*RE	12.69 ***	0.000	59.18 ***	0.000	59.32 ***	0.000	471.9 ***	0.000
*Ln*NRE	9.78 ***	0.000	27.57 ***	0.000	27.70 ***	0.000	235.3 ***	0.000
NR	14.82 ***	0.000	32.93 ***	0.000	33.06 ***	0.000	275.4 ***	0.000
PO	28.79 ***	0.000	106.9 ***	0.000	107.0 ***	0.000	829.1 ***	0.000

Note: *** significant at 1% level of significance. *Ln* is the natural logarithm. Carbon dioxide CO_2 (EQ); Control of corruption (COR); Gross capital formation (GCF); Human development index (HDI); Economic growth (GDP); Technology for renewable energy (TI_R); Technology for non-renewable energy (TI_NR); Renewable energy consumption (RE); Non-renewable energy to primary energy (NRE); Total natural resources rent (NR); Population density (PO).

Data tests against unit root problems are needed to avoid results from spurious regressions. As suggested by earlier studies [7,16], it is possible to test for the presence of unit roots by using the Levin, Lin, and Chu (LLC), the Im, Pesaran, and Shin (IPS), the Augmented Dickey–Fuller (ADF) Fisher, and the PP-Fisher. The panel unit root test (see Table 4) showed that all variables were stationary at the first difference except *Ln*RE using LLC. Using IPS and ADF-Fisher, all variables were stationary at the first difference. Meanwhile, the PP-Fisher suggested that all variables were stationary at the first difference except for PO. In general, it could be said that all variables were free from the unit root problem, so that were eligible for regressions and would not produce spurious regressions.

Table 4. Panel unit root test.

Variables	LLC		IPS		ADF-Fisher		PP-Fisher	
	I(0)	I(I)	I(0)	I(I)	I(0)	I(I)	I(0)	I(I)
*Ln*EQ	−2.31 **	−5.71 ***	0.03	−6.45 ***	18.29	73.78 ***	36.70 ***	132.36 ***
COR	−1.75 **	−2.83 ***	−0.46	−8.79 ***	14.09	100.95 ***	60.27 ***	195.99 ***
*Ln*GCF	−1.46 *	−4.34 ***	−0.99	−7.25 ***	17.69	82.01 ***	14.82	142.02 ***
*Ln*HDI	−5.29 ***	−1.79 **	−1.57 *	−4.04 ***	28.97 **	47.75 ***	54.84 ***	109.20 ***
*Ln*GDP	−1.69 **	−4.12 ***	2.53	−5.59 ***	12.77	61.55 ***	37.41 ***	90.13 ***
*Ln*TI_R	−0.38	−5.75 ***	2.38	−7.85 ***	11.32	88.49 ***	42.69 ***	144.51 ***
*Ln*TI_NR	−3.16 ***	−9.48 ***	−1.31 *	−9.31 ***	22.36	106.51 ***	25.11 *	174.29 ***
*Ln*RE	−2.20 **	−0.96	−1.05	−4.04 ***	31.62 **	44.77 ***	45.01 ***	100.07 ***
*Ln*NRE	−0.08	−7.77 ***	1.52	−9.64 ***	5.85	111.14 ***	7.68	172.02 ***
NR	−0.01	−4.58 ***	−0.74	−8.69 ***	17.89	99.87 ***	41.69 ***	171.24 ***
PO	−5.09 ***	−4.68 ***	−0.74	−3.99 ***	31.69 **	58.18 ***	86.48 ***	9.23

Note: *, **, *** significant at 10, 5, and 1% levels of significance. *Ln* is the natural logarithm.

For the cointegration test, we used the Johansen–Fisher Test following Halliru et al. [7], aiming to validate a long-term relationship between variables [33]. The null hypothesis was that there was no long-term cointegration between variables. The Johansen–Fisher Test for cointegration, as shown in Table 5, rejected the null hypothesis, which indicated that all variables in the sample countries were cointegrated, which meant that a long-run relationship existed between the variables during the period of analysis (1990–2019).

Table 5. Panel cointegration test results.

Hypothesized No. of CE(s)	Fisher Stat. (From Trace Test)	Prob.	Fisher Stat. (From Max-Eigen Test)	Prob.
None	9.704	0.7835	9.704	0.7835
At most 1	9.704	0.7835	9.704	0.7835
At most 2	8.318	0.8721	26.74	0.0208
At most 3	1.386	1	111.9	0

Table 6 shows some selected indicators to better understand the situation of the sample countries. The EQ column indicates the compound average growth rate (CAGR) of the CO_2 emissions. With the exception of Thailand and South Korea, the remaining countries grew a more than 4% annual average in CO_2 emissions. India and Malaysia grew at more than 5% CAGR. Regarding the corruption index (COR), South Korea had the best corruption control index with 0.74, while Pakistan (−0.87) registered the lowest level, followed by the Philippines (−0.57) and Indonesia (−0.42). Regarding gross capital formation (GCF), China maintained an average of 41% in GCP, while the Philippines (21%) and Pakistan (17%) registered the lowest percentages of GFC. In terms of human capital (HDI), South Korea registered the maximum index (0.91) while India (0.65) and Pakistan (0.56) reached the lowest HDI index in 2019. Indonesia, the Philippines, and Thailand showed an average of 0.74 in the HDI Index, with a substantial increase from the beginning to the end of the study period. In terms of economic growth (GDP), China registered a 9.2% annual average growth, while India reached 6%. Indonesia, the Philippines, Thailand and Pakistan registered the lowest GDP growth, on average 3.9% to 4.6% of annual growth.

Table 6. Selected indicators.

Variables	EQ CAGR	COR Avrg	GCF Avrg %	HDI Last	GDP CAGR	TI_R Total (000)	TI_NR Total (000)	RE Avrg %	NRE Avrg %	NR Avrg %	PO CAGR
Philippines	4.3%	−0.57	21%	0.72	4.4%	6.46	82.34	30.9%	3.1%	1.6%	1.9%
China	4.8%	−0.30	41%	0.76	9.2%	9927.08	2064.26	18.8%	3.6%	3.8%	0.7%
India	5.2%	−0.25	32%	0.65	6.0%	187.59	544.01	44.0%	2.3%	3.0%	1.5%
Indonesia	4.2%	−0.42	29%	0.72	4.6%	14.57	129.38	40.8%	0.7%	7.3%	1.3%
S Korea	3.2%	0.74	33%	0.92	4.8%	3005.29	993.67	1.6%	15.8%	0.0%	0.6%
Malaysia	5.1%	0.25	28%	0.81	5.4%	18.90	146.18	5.5%	1.0%	11.5%	1.9%
Pakistan	4.0%	−0.82	17%	0.56	4.0%	2.89	25.94	48.1%	3.4%	1.6%	2.4%
Thailand	3.8%	−0.29	29%	0.78	3.9%	21.00	139.57	22.0%	0.9%	1.8%	0.7%

Note. Compound average growth rate (CAGR); Average (Avrg); Last period (Last); Carbon dioxide CO_2 (EQ); Control of corruption (COR); Gross capital formation (GCF); Human development index (HDI); Economic growth (GDP); Technology for renewable energy (TI_R); Technology for non-renewable energy (TI_NR); Renewable energy consumption (RE); Non-renewable energy to primary energy (NRE); Total natural resources rent (NR); Population density (PO).

The total number of patents related to renewable energy (TI_R) and non-renewable energy (TI_NR) are also shown in Table 6. China and South Korea accumulated the highest number of patents in the period (30 years), while Pakistan registered the lowest number in both indicators. Regarding renewable energy (RE) consumption, Pakistan and India consumed on average about 48% to 44% of energy in renewable types. S Korea, Malaysia, and China had the lowest share of RE among the sample countries. In reference to natural resources (NR), Indonesia and Malaysia had the highest percentages of resources to total GDP. Finally, the population density (PO) increased in all the countries in the sample, but to a greater extent in Pakistan, Malaysia, the Philippines, and India.

4.2. Determinants of Carbon Dioxide (CO_2) Emissions

Table 7 shows the panel quantile regression results. The quantitative regression estimates showed that higher control of corruption (COR) had a negative effect on CO_2 emissions (better environment). However, the results were not significant. A possible explanation for the statistically non-significant result may be because the impact of corruption on CO_2 emissions is indirect, observed through specific policies, as indicated for the case of the G7 countries [43]. Similarly, Sinha et al. [2] stressed that the effects of corruption on CO_2 emissions are manifested indirectly (mediation) through a reduction in the impact of the use of renewable energy and an increase in the negative effects of dirty energy.

Table 7. Panel quantile regression estimates.

Quantiles	COR	*Ln*GCF	*Ln*HDI	*Ln*GDP	*Ln*TI_R	*Ln*TI_NR	*Ln*RE	*Ln*NRE	NR	PO
τ = 0.05	0.001	−0.20 *	−1.58 ***	0.79 ***	0.13 ***	0.016	−0.21 ***	−0.25 ***	0.01 *	6.92×10^{-10} ***
	(0.03)	(0.12)	(0.25)	(0.05)	(0.03)	(0.05)	(0.02)	(0.04)	(0.01)	(1.16×10^{10})
τ = 0.10	−0.04	−0.14	−1.21 ***	0.77 ***	0.12 ***	−0.04	−0.21 ***	−0.23 ***	0.005	8.39 × 10−10 ***
	(0.04)	(0.12)	(0.19)	(0.05)	(0.02)	(0.04)	(0.03)	(0.04)	(0.01)	(1.08 × 10−10)
τ = 0.20	−0.02	−0.1	−1.27 ***	0.73 ***	0.13 ***	−0.01	−0.19 ***	−0.27 ***	0.001	7.60 × 10−10 ***
	(0.03)	(0.06)	(0.16)	(0.03)	(0.02)	(0.03)	(0.03)	(0.02)	(0.003)	(9.98 × 10−11)
τ = 0.30	−0.01	−0.103	−1.34 ***	0.72 ***	0.14 ***	0.01	−0.18 ***	−0.28 ***	0.002	6.89 × 10−10 ***
	(0.04)	(0.07)	(0.19)	(0.04)	(0.02)	(0.04)	(0.03)	(0.02)	(0.003)	(1.10 × 10−10)
τ = 0.40	−0.01	−0.15 **	−1.57 ***	0.73 ***	0.17 ***	−0.002	−0.14 ***	−0.26 ***	0.01	5.58 × 10−10 ***
	(0.04)	(0.07)	(0.18)	(0.04)	(0.03)	(0.05)	(0.03)	(0.02)	(0.004)	(9.71 × 10−11)
τ = 0.50	0.01	−0.13 *	−1.76 ***	0.71 ***	0.22 ***	−0.06	−0.10 ***	−0.24 ***	0.01 **	5.29 × 10−10 ***
	(0.04)	(0.08)	(0.22)	(0.06)	(0.05)	(0.14)	(0.03)	(0.03)	(0.01)	(1.29 × 10−10)
τ = 0.60	−0.01	−0.1	−1.37 ***	0.72 ***	0.22 ***	−0.17 ***	−0.11 ***	−0.22 ***	0.02 **	7.51 × 10−10 ***
	(0.05)	(0.08)	(0.31)	(0.06)	(0.03)	(0.04)	(0.04)	(0.03)	(0.01)	(1.54 × 10−10)
τ = 0.70	−0.05	−0.15 **	−1.16 ***	0.72 ***	0.19 ***	−0.16 ***	−0.15 ***	−0.22 ***	0.01	9.20 × 10−10 ***
	(0.05)	(0.08)	(0.34)	(0.05)	(0.04)	(0.03)	(0.05)	(0.04)	(0.01)	(1.94 × 10−10)
τ = 0.80	−0.06	−0.07	−0.45	0.60 ***	0.15 ***	−0.14 ***	−0.10 *	−0.19 ***	0.002	1.22 × 10−9 ***
	(0.04)	(0.12)	(0.55)	(0.09)	(0.04)	(0.04)	(0.06)	(0.06)	(0.01)	(2.25 × 10−10)
τ = 0.90	−0.02	0.03	−0.08	0.56 ***	0.15 ***	−0.13 ***	−0.02	−0.14 ***	−0.002	1.25 × 10−9 ***
	(0.03)	(0.08)	(0.39)	(0.08)	(0.04)	(0.03)	(0.04)	(0.05)	(0.01)	(1.99 × 10−10)
τ = 0.95	−0.01	0.08	0.03	0.49 ***	0.17 ***	−0.14 ***	0.03	−0.11 ***	0.001	1.28 × 10−9 ***
	(0.03)	(0.07)	(0.33)	(0.05)	(0.03)	(0.03)	(0.03)	(0.04)	(0.01)	(1.64 × 10−10)

Note: *, **, *** significant at 10, 5, and 1% levels of significance. Numbers in brackets are standard error values. Carbon dioxide CO2 (EQ); Control of corruption (COR); Gross capital formation (GCF); Human development index (HDI); Economic growth (GDP); Technology for renewable energy (TI_R); Technology for non-renewable energy (TI_NR); Renewable energy consumption (RE); Non-renewable energy to primary energy (NRE); Total natural resources rent (NR); Population density (PO).

Regarding gross capital formation (GCF), increases in capital helped lower emissions and improved the environment. The results showed that at the 0.05, 0.4, 0.5, and 0.7 quantiles, Asia's gross capital formation was negatively related to CO_2. Higher capital formation relates to increases to capital assets for the country in the form of land improvements, additions of equipment, infrastructure expansion (roads, rails, schools, hospitals, private and public buildings), as well as increases in inventories held by firms. The results suggested that increased capital enables investment in superior technology, undertaking projects, and the upgrading of industrial activities that help emerging Asian countries reduce CO_2 emissions.

As for the human development index (HDI), we found a significant and negative correlation between FDI and CO_2, suggesting that improvements in human capital will improve the environmental sustainability. The results were significant in quantiles 0.1 to 0.7, which suggested that the impact was greater in low-medium quantiles where most of the sample distribution was found. The HDI captures development in human capabilities related to health, education, and quality of life. A negative correlation between the HDI and EQ suggested that as people in emerging Asian countries gain access to better health systems, the more opportunities they have to be more knowledgeable, and as they improve their standards of living, it lowers environmental degradation (CO_2 emissions). These results indicated that investments in human development in Asia had a positive influence on environmental quality.

GDP affected CO_2 emissions as indicated by the positive and significant relationship found in all quantiles. The results revealed that growth in domestic product and income is positively associated with higher carbon dioxide emissions. In this sense, the results suggest that emerging Asia has not exceeded the threshold of environmental degradation exposed in the environmental Kuznets curve. The Kuznets hypothesis indicates that in the initial phase of development, countries experience a positive link between economic growth and environmental degradation up to a point where the growth–CO_2 link becomes negative.

Technology patent application for renewable energy (TI_R) positively affected emissions, meaning that it does not improve environmental quality. The results were significant for all quantiles (0.05–0.95). The results were counterintuitive, as we expected that R&D on renewable energy could help reduce emissions. It is important to note that new technologies in renewable sources such as biomass can generate larger CO_2 emissions than fossil fuels [43,44]. In other words, technologies must be concerned more about making a greener environment and not merely focused on increasing energy production. These results were important considering that the increase in patents is associated with a more extensive use of renewable energies as noted in Tee et al. [45]. However, as the results of this study suggest, further development of renewable technologies does not reduce CO_2 emissions.

Technology patent application of non-renewable energy (TI_NR) had a negative impact on CO_2 emissions, meaning that R&D projects can positively affect environmental sustainability. The results were significant in high quantiles (0.6–0.95).

Renewable energy consumption (RE) had a negative effect on CO_2 emissions as indicated in the statistically significant results in quantiles 0.05 to 0.8. In other words, increasing the consumption of renewable sources helped decrease CO_2 emissions, offering opportunities to increase environmental quality. Increased use of renewable energy (i.e., geothermal, solar, hydroelectric, biomass waste, biofuels, or wood) could help Asian countries reduce CO_2 emissions. As for the share of non-renewable energy to primary energy (NRE), it had a negative effect on CO_2 emissions on all quantiles (0.05 to 0.95). The result was somehow opposite of previous research stating that non-renewable energy use leads to higher emissions in developing countries [2,10]. However, some emerging Asian countries are reducing non-renewable sources and substituting them with renewable sources, signaling that energy policies have helped achieve higher environmental quality. A recent study provided evidence in the case of Malaysia [46], where emissions were reduced through diversification in the production and use of energy towards sources other than oil and coal.

Meanwhile, abundance in natural resources (NR) positively affected environmental degradation. The results were significant in the low (0.05) and middle quantile (0.5 and 0.6) and not significant for the higher quantiles.

Population density (PO) positively affected carbon emissions, which meant higher density led to environmental degradation. The results were significant for all quantiles. Population density refers to the number of inhabitants per square kilometer of area. In China, the population density increased from 120 to 149 inhabitants per sq km (similar to Indonesia). In Pakistan, PO increased from 139 to 280, while in India, the increase was from 293 to 460 inhabitants per sq km. Thus, it could be inferred that increasing levels of population density had supported larger CO_2 emissions in Asia.

4.3. Discussion

Table 8 summarizes the estimates (a sign of impact) of the quantile results in Table 7.

The results of this study did not provide evidence of a statistically significant relationship between corruption control (COR) and environmental quality (EQ). Previous research also showed mixed results. Using the environmental performance index as an indicator of environmental quality for a large sample of countries, Lisciandra and Migliardo [12] found that increases in levels of corruption reduce environmental quality. Other studies also found a positive relationship between corruption and environmental damage as in Rehman et al. [47] (South Asian countries) and Sinha et al. [2] (BRICS). Some studies found significant results at high quantiles as in Luqman et al. [27] for the case of Pakistan, while others did not find any significant results, as in Azam and Khan [6] for the case of Malaysia, Indonesia, and Thailand, or Haldar and Sethi [10] for a sample of developing countries. One possible explanation is linked to the improvement in the corruption control index that was observed in the Asian countries covered in this study. However, it is also true that the index showed large fluctuations during the period of analysis, without showing a constant trend.

Table 8. Summary of quantile regression estimates.

Variables	Low (τ = 0.05 until 0.30)	Middle (τ = 0.40 until 0.60)	High (τ = 0.70 until 0.95)
COR	/	/	/
*Ln*GCF	−	−	−
*Ln*HDI	−	−	−
*Ln*GDP	+	+	+
*Ln*TI_R	+	+	+
*Ln*TI_NR	/	−	−
*Ln*RE	−	−	−
*Ln*NRE	−	−	−
NR	+	+	/
PO	+	+	+

Note: *Ln* is the natural logarithm, "/" indicates no significant effect, "−" indicates a negative impact, and "+" indicates a positive effect of the independent variable on the dependent variable. Carbon dioxide CO_2 (EQ); Control of corruption (COR); Gross capital formation (GCF); Human development index (HDI); Economic growth (GDP); Technology for renewable energy (TI_R); Technology for non-renewable energy (TI_NR); Renewable energy consumption (RE); Non-renewable energy to primary energy (NRE); Total natural resources rent (NR); Population density (PO).

Regarding gross capital formation (GCF), the results of this study supported earlier evidence, such as the one presented by Shahbaz et al. [43] stating that capital formation helps lower emissions in high-income countries (G7) and APEC countries [19]. Other studies showed that capital formation can drive emissions, while others claimed a bidirectional relation between finance and CO_2 (e.g., BRICS in Rafique et al. [3]). In the BRICS countries, foreign capital improved the environmental sustainability in China, but the remaining countries (Brazil, India, Russia, and South Africa) showed mixed results. This study (Tables 7 and 8) provided new evidence on the positive effect of capital on the environmental quality of emerging countries in Asia, previously not found in studies using a similar method (e.g., a quantile approach in Haldar & Sethi [10]). It is possible that earlier studies [10] over specified the model by including variables that are overlapped (FDI, domestic credit, gross capital formation, among others).

Regarding the HDI—CO_2 nexus, this study validated policies in support of human development in emerging Asia as they had effects in favor of environmental quality. Earlier studies also considered HDI or sub-components, e.g., education in APEC ([19] or [48]), finding that higher levels of HDI or sub-components help lower emissions. In China, human capital improvement (e.g., education) lowered CO_2 emissions [49], but in other studies, human capital improvement resulted in higher emissions as in West African states [7] or Pakistan [50].

The results provided evidence on the positive nexus between economic growth (GDP) and CO_2 emissions in the eight Asian countries examined in this study. The findings of this study are in line with earlier evidence, stating that economic growth in Asia continues to be a significant contributor to environmental degradation (see, e.g., [10,19,21,51]). In Pakistan, India, and Bangladesh, Mehmood et al. [26] found similar results to the ones in this study, stating that good governance should accompany economic growth for emissions to decline.

Regarding the link between patents in renewable energies and CO_2, the results indicated that CO_2 emissions are linked to the increase in patents related to renewable energies. R&D or higher technology in APEC countries result in larger CO_2, as noted by Zafar el al. [19]. The results presented in this study also align with Allard et al. [16] who used quantile regression and found that R&D was positively associated with CO_2 emissions in low and middle-income countries. Improvements in technology can help decrease emissions in higher income economies in the APEC region [19,52], G7 countries [23,51], or for high-income level countries [16], but not in emerging Asia. It is perhaps necessary to accompany the development of renewable energy technologies with efficiency in generation, distribution, and consumption of energy.

Considering that technology for non-renewable energy (TI_NR) showed a negative relation to CO_2 emissions, this study then suggests that energy policies in Asia may shift towards cleaner energy by supporting technological development. Access to more advanced technologies can help reduce emissions, probably associated with more efficient production, distribution, and use of energy. In line with the Kuznets hypothesis, economic expansion in Asia may be associated with an increase in per capita energy consumption due to higher population and income, but also with the inappropriate use of technologies to produce and consume energy. The findings of this study supported previous evidence that showed that technological innovation can reduce CO_2 in Brazil [11], the BRICS [3], and G7 countries [43]. Energy policies in Asia may lean towards cleaner energy by supporting technological improvements in power generation, not necessarily green sources. Nevertheless, the results were also counterintuitive to the findings of Jiao et al. [53] in China, Santra [54] for some BRICS countries, and Zafar et al. [19] for APEC, who found that innovation in non-renewable technologies drives CO_2 emissions.

Regarding renewable energy consumption (RE), this study found results that align with earlier studies in advanced and BRICS countries (see [10,23,48,51,55]). Employing a similar approach on a large dataset of countries, Allard et al. [16] also found a negative correlation between renewable sources and CO_2, maintaining that green energy sources can improve the environment. Within Asia, the findings differed from a recent study for India, Pakistan, and Bangladesh, whereby non-renewable and renewable energy use drives more emissions [26].

Among the eight countries included, the available natural resources are abundant in countries like Indonesia, Malaysia, and China, suggesting the need for environmental protection policies that are directly linked to natural resources. Previous studies in BRICS countries yielded mixed results [13,56]. Evidence from this study supported those of Masron & Subramaniam [29] who pointed out the need for more robust policies to manage natural resources to reduce pollution and greenhouse emissions in developing countries. Furthermore, earlier studies in the BRICS [13] and other regions [57], looking into the biocapacity perspective (productive land and available water for human consumption), noted that exploitation of resources can accelerate environmental degradation as the capacity to absorb pollutants decreases. As such, Asian countries need a more active policy in protecting the ecology in the region as emissions can lower the biological ability to absorb pollutants.

The evidence of this study is in line with previous findings stating that a rise in population and urban development was identified as one of the major determinants of CO_2 emissions in the BRICS [2,3], G7 [43], and emerging Asian countries [10].

Regarding the Kuznets hypothesis, which establishes that economic expansion drives emissions in three channels, this study provided evidence on the following aspects. First, in the eight Asian countries examined, energy consumption is associated with higher economic growth and population density (scale effect in Kuznets). Second, the fact that CO_2 emissions are negatively associated with renewable energy consumption suggests that better energy choices can help improve sustainable development in Asia. Finally, this study provided evidence that emissions in Asia can be improved through better choice of technologies (production, distribution, and use of energy). Increasing the use of working capital and the use of more advanced energies can reduce the environmental impact. The positive link between GDP growth and CO_2 emissions suggests that the eight countries observed in this study appear not to have reached the threshold of the environmental curve.

The three channels exposed in the Kuznets hypothesis can serve as a reference to proposals for environmental policies. There are opportunities to reduce CO_2 emissions through the three channels: scale of consumption, energy composition, and choice of technologies. For Asian countries, a way to reach the environmental threshold in the Kuznets hypothesis could be by increasing investments in human development, investing in new technologies to increase efficiency in power generation (i.e., TI_NR), increasing working capital (GCF), and migrating to more environmentally friendly energy consumption (RE).

4.4. Policy Recommendations and Implications

In accordance with the findings of this study, the following policy implications were drawn: Firstly, the investment in research and development is not enough. Hence, the government should focus on R&D investment to improve their technology innovation effectiveness to achieve the dual effect of growth with environmental quality. Secondly, the empirical results proved that the patents on renewable energy contribute more to carbon emission. On the other hand, the patents on non-renewable energy improve the quality of the environment by reducing carbon ejection. Although energy technology patents have significantly increased, many energy-efficient technologies have not been widely adopted. Hence, the government should design energy structures and develop zero carbon-emitting energy technologies. Thirdly, low income and middle-income countries should pay particular concern to the benefits of technology innovation and proactively participate with other developed countries to stimulate the utilization of environmentally friendly technologies. Countries should shift from an energy-driven economy to an innovation-driven economy to curb emissions and achieve sustainable development, specifically high carbon-emitting countries.

Fourthly, development in human capital formation is a critical requirement to achieve economic growth and sustainable development. Human capital plays a vital role, by stimulating research and development on energy-efficient technology. The results also support improving the level of the HDI, which causes the quality of human capital to flourish through education. Fifthly, the results also found that both renewable and non-renewable energy negatively affect carbon emissions, which was quite unexpected. Energy consumption, especially non-renewable energy, is the main driver for economic growth for emerging countries, which causes environmental degradation. So, it is essential to maintain the energy sector to achieve sustainability without compromising growth. Therefore, the policymakers should prioritize obtaining an optimum mixture of both renewable and non-renewable energy, aiming to meet the nation's requirements and environmental needs. Lastly, to achieve sustainability, a long-term strategic policy is needed to improve the efficiency of energy by investing in renewable energy sources like solar, wind, geothermal, and biofuels to achieve sustainable development in emerging Asian countries

5. Conclusions

We estimated the link between technological innovation, renewable energy use, governance, and human capital and the carbon emissions in China, South Korea, India, Pakistan, Indonesia, Thailand, Malaysia, and the Philippines, with data from 1990 to 2019. We employed a quantile regression approach in the analysis. The findings suggested that improvements in technological innovation in non-renewable energies, human resource development, capital formation, and renewable energy use can help reduce emissions. Meanwhile, patents (proxies for R&D) positively relate to CO_2 emissions, which means that not all technological developments are linked to better environmental quality.

On the other hand, economic growth, population density, and energy consumption drive emissions. Therefore, investments in human capital, technological innovation, and renewable energies need to go hand in hand with economic growth to reduce the impact on the environment. The use of greener energy and good governance could also help lower emissions. Finally, we also found that energy consumption was not the only source of emissions. The extraction of natural resources can also cause more carbon footprint. Asian countries, rich in natural resources, need to reconsider policies towards more sustainable management of natural resources as this is closely linked to CO_2 emissions (at least in lower and middle quantiles).

There are opportunities to reduce CO_2 emissions through the three channels exposed in the Kuznets hypothesis: scale of consumption, energy composition, and choice of technologies. For Asian policy makers, policies should focus on human capital and R&D investment to improve technology innovation effectiveness to achieve the dual effect of growth with environmental quality. More attention paid to increasing investments in human development, investing in higher technologies to increase efficiency in generation, distribution, and use of power can help to lower CO_2 emissions. Migrating to more environmentally friendly energy consumption can help to improve environmental quality, although choosing appropriate technologies to generate clean energies is needed.

Regarding the choice of panel quantile regression as a research tool, the approach was selected as it could accommodate differences in the distribution of variables so that better information could be extracted from them. Panel quantile regression provides a regression model at all quantile levels, based on a conditional distribution of the data, suitable for samples with outliers. As a result, a quantile regression captures a different slope for each quantile, a consideration often missed in previous studies.

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