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Tourism, Environment, and Growth: A Quantile Regression Analysis

Abstract. *This study investigates the environmental effects of tourism revenues by applying the Method of Moments Quantile Regression (MMQREG) to a panel of high-income tourism economies over the period 2005–2020. The results demonstrate that the impact of tourism revenues depends on their measurement. In nominal terms (billion USD), tourism revenues consistently increase carbon emissions across all quantiles. However, when expressed as a share of GDP or total exports, tourism revenues show positive effects at lower quantiles, but negative effects at higher quantiles. Panel causality analysis further reveals a unidirectional causal relationship from tourism revenues as a share of exports to carbon emissions. These findings underscore the importance of variable specification in econometric analysis and highlight the structural role of tourism in shaping environmental outcomes. The policy implications suggest that strategies should be tailored to countries' emission profiles, recognising the heterogeneous impact of tourism on environmental sustainability.*

Keywords: *tourism revenues, CO_2 emissions, environment, panel quantile regression, causality.*

JEL Classification: C32, Q53, Q56.

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1. Introduction

Tourism is a major driver of economic growth, employment, and foreign exchange earnings, yet it also raises concerns about environmental sustainability. Its dual role – generating income while contributing to carbon emissions – has led to mixed empirical evidence. While some studies report a positive association between tourism and emissions, others suggest that tourism can support environmental quality through technology transfer, standards, and investment in green practices.

Given these divergent findings, this study investigates the impact of tourism revenues on carbon emissions across the 20 largest tourism economies. A distinctive feature is the use of three measures of tourism revenues: nominal value, share of GDP, and share of exports. This multidimensional approach enables a deeper understanding of how the structural role of tourism influences environmental outcomes.

Methodologically, the study employs the Method of Moments Quantile Regression (MMQREG), which allows analysis across the emissions distribution and accounts for heterogeneity and non-normality in the data. To reinforce robustness, a Fixed Effects estimator with Driscoll–Kraay standard errors is also applied. By integrating multiple measures of tourism revenues with an advanced econometric approach, the study contributes to the debate on the tourism–environment nexus and offers differentiated policy insights for economies at varying emission levels.

This study advances the literature by integrating a multidimensional conceptualisation of tourism revenues with an innovative methodological framework capable of capturing heterogeneity and distributional effects. The insights derived from this approach offer important policy implications, suggesting that the environmental impact of tourism is not uniform, but varies significantly depending on a country’s economic structure and its position in the emissions distribution. These findings highlight the need for tailored and context-specific policy interventions to harness tourism’s economic benefits while minimising environmental costs.

The remainder of this paper is structured as follows. Section 2 reviews the relevant literature on the environmental impacts of tourism. Section 3 describes the data, variable definitions, and econometric methodology, including the rationale for employing the MMQREG and FE-DK estimators. Section 4 presents the empirical results and a discussion, while Section 5 concludes with a summary of the main findings and policy implications.

2. Literature review

The environmental implications of tourism have become a prominent research theme in recent decades, but the empirical evidence remains inconclusive. A substantial stream of studies emphasises the adverse role of tourism in increasing carbon emissions, particularly due to the sector’s heavy reliance on transportation, accommodation, and other energy-intensive services. Katircioglu (2014), for instance, identifies a long-run equilibrium among tourism, energy consumption, and CO_2 emissions in Turkey, underscoring the dependency of tourism on fossil fuels. Similarly, Al-Mulali et al. (2013) demonstrate that tourist arrivals significantly increase transport-related emissions across most destinations, although the effect is weaker in Europe, where stringent environmental regulations prevail. Further evidence from Pakistan (Sharif et al., 2017) and the European Union (Lee & Brahmasrene, 2013) corroborates the view that tourism expansion, while fostering growth, contributes to environmental degradation.

Contrasting perspectives suggest that tourism may also enhance environmental sustainability under certain conditions. Using panel quantile regression, Aslan et al. (2021) show that tourism's contribution to growth in Mediterranean countries supports environmental quality at lower development levels but becomes insignificant as growth accelerates. Yiğit et al. (2024) confirm quantile-dependent impacts of tourist arrivals on transport-related emissions, highlighting the heterogeneity of outcomes across countries. Evidence from Turkey further illustrates this structural dimension: Bahar and Demir (2023) find that while international arrivals exacerbate emissions, tourism revenues reduce them, suggesting that the relative economic role of tourism is as important as its scale. Similarly, Azam et al. (2018) identified positive effects of tourism on emissions in Malaysia but negative ones in Singapore and Thailand, reinforcing the context-specific nature of the results.

Recent contributions have expanded the debate by incorporating globalisation, asymmetries, and institutional quality. Uzuner et al. (2020) show that positive and negative tourism shocks affect emissions asymmetrically in Turkey. Alola et al.'s study (2021) demonstrates that in OECD countries, tourism, urbanisation, and energy use exert significant but quantile-varying effects on emissions, with the Environmental Kuznets Curve (EKC) hypothesis supported only at lower income levels. Zaman et al. (2016) and Zhang and Gao (2016) similarly emphasise regional differences, reporting that the tourism-induced EKC hypothesis holds in some regions but not others.

An emerging strand of research highlights the role of innovation, renewable energy, and institutional capacity in shaping the tourism–environment nexus. Tong et al. (2022) show that tourism indirectly mitigates emissions in Chinese cities through openness, environmental regulation, and innovation, despite its direct positive effect. Avcı et al. (2024) provide evidence that green technological innovation and renewable energy consumption moderate tourism's environmental costs in the most-visited countries. Wei and Ullah (2022) identify heterogeneous effects of tourism across the emissions distribution in Asian economies, while Ohajionu et al. (2022) highlight tourism's potential to reduce emissions when combined with financial development. Comparative analyses by Paramati et al. (2017) reinforce these findings, showing that tourism-driven growth in developed economies is associated with lower environmental costs, consistent with the EKC hypothesis.

Overall, the literature converges on the view that the environmental impact of tourism is heterogeneous, shaped by structural, institutional, and developmental factors. Tourism may exacerbate emissions in carbon-intensive and weakly regulated contexts, yet it can simultaneously drive sustainability through technological innovation, renewable energy adoption, and strong governance. These insights underscore the importance of adopting differentiated policy strategies tailored to countries' specific economic structures and emission profiles.

Unlike previous studies in the literature, this study analyses the impact of tourism revenues on carbon emissions by employing different representations of tourism revenues (nominal value, share of GDP, share of exports). This approach allows for testing whether structural differences arise depending on how tourism is positioned within the economy, thereby providing deeper insights into the environmental effects of tourism beyond its absolute size.

3. Data, Model, Method, and Findings

3.1 Data and Model

This study analyses the impact of tourism revenues on carbon emissions for a sample of the 20 countries1 with the highest tourism revenues from 2005 to 2020. Table 1 presents the variables used to examine the environmental impact of international tourism revenues and energy consumption. Carbon emissions (lnco2) are employed as the dependent variable in models. The independent variables include tourism revenues (lntur1), the share of tourism revenues in GDP (lntur2), the ratio of tourism revenues to exports (lntur3), per capita income (lngdppc), globalisation index (lnglob), fossil fuel consumption (lnfossil), and renewable energy consumption (lnren).

Table 1. Data set

Variable	Definition
lnco2	Carbon dioxide (CO2) emissions excluding GHG fluxes caused by Land Use Change, Land Use, and Forestry (LULUCF) per capita (t CO2e/capita)
lntur1	International tourism, receipts (current US$)
lntur2	International tourism, receipts (% of GDP)
lntur3	International tourism, receipts (% of total exports)
lngdppc	GDP per capita (current US$)
lnglob	KOF Swiss Economic Institute Globalisation Index

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[1] These countries were selected from among the top 30 countries in terms of tourism revenues as of 2020, based on the availability of consistent data. The selected countries are: Australia, Croatia, Egypt, France, Greece, Hungary, Indonesia, Ireland, Japan, South Korea, Luxembourg, Mexico, Morocco, Poland, Portugal, Russia, Switzerland, Thailand, Türkiye, and the United States.

Variable	Definition
lnfossil	Fossil fuel energy consumption (% of total)
lnren	Renewable energy consumption (% of total final energy consumption)

Source: World Bank Databank, World Development Indicators, KOF Swiss Economic Institute.

Table 2 represents the descriptive statistics of the variables used in the econometric analysis. Regarding the skewness values, the variables lntur1 and lntur3 exhibit positive skewness, indicating their right-skewed distributions. Conversely, the variables lnco2, lngdppc, lntur2, lnglob, lnren, and lnfossil have negative skewness values, suggesting left-skewed distributions. Regarding kurtosis, the variables lnren and lnfossil have kurtosis values greater than 3, indicating that their distributions peaked more than normal. On the other hand, the variables lnco2, lngdppc, lnglob, lntur1, lntur2, and lntur3 have kurtosis values lower than 3, implying flatter distributions relative to normal. The Jarque-Bera test statistics indicate whether the series follows a normal distribution and is statistically significant for all variables. This result confirms that none of the variables is normally distributed. In panel data analysis, the assumption of normality is not required and thus does not affect the validity of the results (Özaydın and Yeşilkaya, 2020, p. 171). The study covers 20 cross-sectional units (N) over 12 years (T), resulting in 320 observations.

Table 2. Descriptive statistics

Variables	lnco2	lngdppc	lntur1	lntur2	lntur3	lnglob	lnren	lnfossil
Mean	1.8298	9.7767	2.0930	1.0815	2.0930	4.276	2.340	4.388
Median	1.7498	9.7600	2.0184	1.0873	2.0184	4.299	2.393	4.438
Max.	3.2597	11.7254	3.8265	2.9693	3.8265	4.510	3.728	4.567
Min.	0.3856	7.0074	-0.3837	-1.6041	-0.3837	3.929	-0.105	3.846
Std. Dev.	0.6963	1.1137	0.8518	0.9646	0.8518	0.132	0.765	0.179
Skewn.	-0.1188	-0.2901	0.1020	-0.3503	0.1020	-0.443	-0.621	-1.738
Kurtosis	2.3144	2.2642	2.2340	2.7711	2.2340	2.637	3.269	5.224
Jarque-Bera	7.0192	11.7065	8.3790	7.2461	8.3790	12.24	21.58	227.1
Prob.	0.0299	0.0028	0.0151	0.0267	0.0151	0.002	0.000	0.000
Sum	585.536	3128.58	669.782	346.098	669.782	1368.447	749.0876	1404.286
Sum Sq. Dev.	154.6952	395.7159	231.4553	296.8392	231.4553	5.5889	186.9811	10.2624
Obs.	320	320	320	320	320	320	320	320

*Sourc*e: Authors' computation.

Three different models have been constructed to test the effects of tourism revenues on carbon emissions. The studies that informed the construction of the models include Avcı et al. (2024), Alola et al. (2021), Faisal and Ebrahimi-Salari (2023), Zhang and Zhang (2022), Wei and Ullah (2022), Ohajionu et al. (2022), and Yiğit et al. (2024).

These models are as follows:

Model 1: $lnCO_{2it} = a + \beta_1 lntur1_{it} + \beta_2 lngdppc_{it} + \beta_3 lngdppc2_{it} + \beta_4 lnglob_{it} + \beta_5 lnren_{it} + \beta_6 lnfossil_{it} + \varepsilon_{it}$

Model 2: $lnCO_{2it} = a + \beta_1 lntur2_{it} + \beta_2 lngdppc_{it} + \beta_3 lngdppc2_{it} + \beta_4 lnglob_{it} + \beta_5 lnren_{it} + \beta_6 lnfossil_{it} + \varepsilon_{it}$

Model 3: $lnCO_{2it} = a + \beta_1 lntur3_{it} + \beta_2 lngdppc_{it} + \beta_3 lngdppc2_{it} + \beta_4 lnglob_{it} + \beta_5 lnren_{it} + \beta_6 lnfossil_{it} + \varepsilon_{it}$

3.2 Method

To examine the environmental impact of international tourism revenues and energy consumption, this study employs the Method of Moments Quantile Regression (MMQREG) approach proposed by Machado and Santos Silva (2019). In addition, the Fixed Effect Model with Driscoll-Kraay standard errors (FE-DK) is also used to assess the robustness of the findings.

The rationale behind choosing the quantile regression method in this study can be explained as follows: According to Koenker and Bassett (1978), when variables do not follow a normal distribution and the variance of the error term is not constant, regression estimators become biased and inconsistent. To address these issues, the panel quantile regression model is recommended. Quantile regression specifically considers the entire distribution and is also motivated by the desire to potentially control for heterogeneity and time-varying problems of outliers (Barışık and Ergen, 2023; Alola et al., 2021). In our study, the Jarque-Bera test statistics for the variables were statistically significant (Table 2), indicating that the variables do not follow a normal distribution. This non-normality constitutes the first reason for selecting the quantile regression model. Secondly, our aim to investigate whether the impact of tourism revenues on carbon emissions differs across quantile levels (i.e., at different levels of carbon emissions) is the second motivation behind the model choice.

The panel quantile regression model initially proposed by Koenker and Bassett (1978) estimates the dependent variable’s conditional mean and variance based on the explanatory variables’ values (Zhang and Zhang, 2023: 1194). Unlike conventional linear estimators that focus on mean effects, the MMQREG method can more effectively handle the distributional characteristics of the data. Standard quantile regression may yield non-monotonic estimates across multiple quantiles, potentially resulting in invalid distributions. In contrast, MMQREG minimises such limitations, especially when combined with fixed effects in panel settings (Khan and Hassan, 2024, p. 5). This estimator captures the heterogeneous and distributional impacts of independent variables across different quantiles of both location and scale (Zhang et al., 2024, p. 5). It does not require normality and provides robust and efficient estimates in the presence of outliers. Overall, MMQREG offers a more flexible and reliable approach for accurately estimating the effects of explanatory variables under conditional heterogeneity (Khan et al., 2023).

The equation used to approximate the conditional quantile location-scale variant $Q_Y(\tau|R)$ can be expressed as follows:

$$Y_{it} = \gamma_i + aR_{it} + (\sigma_i + \varphi X_{it})\mu_{it} \qquad (1)$$

The equation is expressed as $(\sigma_i + \varphi.X_{it} > 0) = 1$. In this formulation, γ $\gamma, a, \sigma,$ and φ are the estimated coefficients. The term i is represented by γ_i and σ_i for $i = 1,2, \dots n$ captures the fixed effects. The standard components of R are denoted by a k-vector X, which represents a characteristic variation with I elements (Hassan et al., 2023, p. 9).

Furthermore, the components are further transformed with the component I illustrated as:

$$XI = XI(R), I = 1, \dots, K \qquad (2)$$

Here, μ_{it} is orthogonal to the R_{it} component and strictly satisfies the moment conditions without imposing strong heterogeneity assumptions. Therefore, the conditional quantiles of Y are expressed as follows:

$$Q_\tau\left(\frac{\tau}{R_{it}}\right) = \left(\gamma_i + \sigma_i q(\tau)\right) + aR_{it} + \varphi X_{it} q(\tau) \qquad (3)$$

The equation specifies R_{it} as the set of explanatory variables, which includes: lngdppc, lngdppc2, lntur1, lntur2, lntur3, lnglob, lnfossil, and lnren. This study models the conditional quantile distribution of the dependent variable (Y_{it}, carbon emissions) as a function of explanatory variables (R_{it}) and their location in the distribution. The term $\gamma_i(\tau) = \gamma_i + \sigma_i q(\tau)$ captures individual fixed effects at quantile τ, where the intercept remains invariant across individuals. As regressors are time-invariant, their effects are allowed to vary across quantiles. The analysis focuses on the 25th, 50th, 75th, and 90th quantiles (Hassan et al., 2023, p. 9; Khan & Hassan, 2024, p. 5; Ohajionu et al., 2022, pp. 30010- 30011).

The models to be estimated using the MMQREG method can be represented as follows:

$$\begin{aligned} Q_{y_t}(\tau|X) = \beta_0(\tau) &+ \beta_1(\tau) lntur1_{1t} \\ &+ \beta_2(\tau) lngdppc_{2t} + \beta_3 lngdppc_{3t}^2 + \beta_4(\tau) lnfossil_{4t} \\ &+ \beta_5(\tau) lnren_{5t} + \beta_6(\tau) lnglob_{6t} + \varepsilon_t \end{aligned}$$

$$\begin{aligned} Q_{y_t}(\tau|X) = \beta_0(\tau) &+ \beta_1(\tau) lntur2_{1t} \\ &+ \beta_2(\tau) lngdppc_{2t} + \beta_3 lngdppc_{3t}^2 + \beta_4(\tau) lnfossil_{4t} \\ &+ \beta_5(\tau) lnren_{5t} + \beta_6(\tau) lnglob_{6t} + \varepsilon_t \end{aligned}$$

$$\begin{aligned} Q_{y_t}(\tau|X) = \beta_0(\tau) &+ \beta_1(\tau) lntur3_{1t} \\ &+ \beta_2(\tau) lngdppc_{2t} + \beta_3 lngdppc_{3t}^2 + \beta_4(\tau) lnfossil_{4t} \\ &+ \beta_5(\tau) lnren_{5t} + \beta_6(\tau) lnglob_{6t} + \varepsilon_t \end{aligned}$$

3.3 Findings

In the study, the presence of cross-sectional dependence among the variables was initially tested using the weak cross-sectional dependence test proposed by Pesaran (2014). According to the findings presented in Table 3, the null hypothesis is rejected for all variables. Therefore, there is strong cross-sectional dependence among the cross-sectional units.

Table 3. Pesaran (2015) CD Test

Variable	CD-test	p-value
lnco2	6.294	0.000
lntur1	40.955	0.000
lntur2	33.557	0.000
lntur3	33.48	0.000
lngdppc	27.399	0.000
lnren	13.066	0.000
lnfossil	14.234	0.000
lnglob	27.014	0.000

Notes: Under the null hypothesis of cross-section independence, CD ~ N(0,1), P-values close to zero indicate data are correlated across panel groups.

Source: Authors' computation.

The heterogeneity of slope coefficients is examined using the robust standard error test developed by Blomquist and Westerlund (2013). According to the findings presented in Table 4, the null hypothesis suggesting that slope coefficients are homogeneous is rejected in all models, both in small and large sample cases. Therefore, it is concluded that the slope coefficients in the models are heterogeneous.

Table 4. Blomquist and Westerlund (2013) slope heterogeneity test

Model	Delta test
Model 1	$\tilde{\Delta}$ = 9.225, prob.= 0.000 $\tilde{\Delta}_{adj}$ = 13.045, prob.= 0.000
Model 2	$\tilde{\Delta}$ = 7.151, prob.= 0.000 $\tilde{\Delta}_{adj}$ = 10.112, prob.= 0.000
Model 3	$\tilde{\Delta}$ = 4.074, prob.= 0.000 $\tilde{\Delta}_{adj}$ = 5.761, prob.= 0.000

Note: H_0: slope coefficients are homogeneous.

Source: Authors' computation.

Table 5 presents the results of the Pesaran (2007) CIPS unit root test. In the model with only an intercept, the variables *lntur1* and *lnglob* are stationary at level, whereas none are stationary in the model with an intercept and trend. Due to the non-stationarity of the variables, their first differences were taken, and the unit root test was repeated. At first differences, the variables *lntur2, lntur3, lnren,* and *lnfossil* became stationary in intercept-only and intercept-and-trend specifications. However, the variables *lnco2*, *lngdppc*, *lntur1*, and *lnglob* remained non-stationary. When the second differences of these variables were taken, they were found to be stationary.

Table 5. Pesaran (2007) CIPS Test

Variable	**LEVEL**		**FIRST DIFFERENCES**		**SECOND DIFFERENCES**	
	Constant	**Constant and Trend**	**Constant**	**Constant and Trend**	**Constant**	**Constant and Trend**
lnco2	-1.48287	-1.61522	-2.6356***	-2.59240	-3.3220***	-3.41763***
lntur1	-2.4121**	-1.79631	-2.5007***	-2.38081	-2.8494***	-4.51589***
lntur2	-1.75270	-2.24672	-3.1399***	-3.1729***	-	-
lntur3	-1.25041	-2.44951	-3.0528***	-2.67451*	-	-
lngdppc	-1.88711	-2.49155	-2.6719***	-2.63846	-4.4613***	-3.53473***
lnren	-1.92283	-1.99986	-2.34247**	-3.1784***	-	-
lnfossil	-1.79566	-2.44625	-2.9436***	-3.4106***	-	-
lnglob	-2.2683**	-1.79705	-2.34937**	-2.14162	-3.2757***	-3.72455***

Source: Authors' computation.

The findings obtained from the FE-DK and MMQREG analysis, which investigates the impact of tourism revenues and energy consumption on carbon emissions, are presented below. Model 1, which uses the current value of tourism revenues, reports estimates across five different quantile levels (qtile_10, qtile_25, qtile_50, qtile_75, qtile_90). The results are summarised in Table 6.

According to the findings obtained from the FE-DK estimator, per capita income, tourism revenues, and fossil fuel consumption have a positive and statistically significant effect. In contrast, renewable energy consumption has a negative and statistically significant effect.

The table of MMQREG findings shows that the variable lngdppc is positive and statistically significant in all quantiles. At the same time, the squared term representing income per capita (lngdppc2) is negative and statistically significant at the 10th, 25th, and 50th quantiles. This suggests that as per capita income increases, carbon emissions initially rise; however, after a certain income level, further increases in income lead to a reduction in carbon emissions. This finding confirms the validity of the Environmental Kuznets Curve (EKC) hypothesis (inverted-U shape) for the countries included in the analysis.

Tourism revenues have a statistically significant and positive effect on carbon emissions across all quantiles; however, the strength of this effect weakens as the quantile level increases. The weaker impact of tourism revenues on carbon emissions in high-emission countries can be explained by the dominance of structurally carbon-intensive sectors such as industry and energy, which reduce the relative influence of tourism on total emissions (Paramati et al., 2017; Koenker & Hallock, 2001).

Other variables that have a statistically significant positive impact on carbon emissions include lnglob (globalisation index) and lnfossil (fossil fuel consumption). These results indicate that increases in globalisation and fossil fuel use contribute to higher carbon emissions. The impact of fossil fuel consumption and globalisation on carbon emissions increases as the quantile level rises. On the other hand, renewable energy consumption (ren) is found to have a negative effect on carbon emissions.

Table 6. FE-DK and MMQREG results for model 1

Quantiles	**(1)**	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**	**(7)**	**(8)**
Variables	**FE-DK**	**location**	**scale**	**qtile_10**	**qtile_25**	**qtile_50**	**qtile_75**	**qtile_90**
lngdppc	0.22***	1.449***	-0.64***	2.45***	2.13***	1.45***	0.85***	0.489
	(0.0687)	(0.253)	(0.133)	(0.300)	(0.289)	(0.269)	(0.291)	(0.341)
lngdppc2	-0.0069	-0.051***	0.032***	-0.10***	-0.08***	-0.051***	-0.0219	-0.00330
	(0.0045)	(0.0130)	(0.0067)	(0.0151)	(0.0146)	(0.0138)	(0.0150)	(0.0175)
lntur1	0.024**	0.08***	-0.03***	0.13***	0.11***	0.084***	0.055***	0.0377*
	(0.0089)	(0.0160)	(0.0075)	(0.0180)	(0.0172)	(0.0165)	(0.0184)	(0.0205)
lnglob	0.0459	0.403**	0.29***	-0.0555	0.0913	0.403*	0.67***	0.84***
	(0.0580)	(0.204)	(0.0823)	(0.263)	(0.251)	(0.208)	(0.195)	(0.210)
lnren	-0.18***	-0.25***	-0.0135	-0.23***	-0.23***	-0.25***	-0.26***	-0.27***
	(0.0138)	(0.0225)	(0.0140)	(0.0208)	(0.0189)	(0.0225)	(0.0314)	(0.0385)
lnfossil	1.24***	1.213***	0.37***	0.63***	0.81***	1.212***	1.55***	1.76***
	(0.0751)	(0.0938)	(0.0411)	(0.129)	(0.130)	(0.105)	(0.0852)	(0.0842)
Constant	-5.4***	-15.7***	1.234*	-17.7***	-17.0***	-15.7***	-14.6***	-13.9***
	(0.579)	(1.511)	(0.709)	(1.632)	(1.498)	(1.524)	(1.796)	(2.061)
Obs.	320	320	320	320	320	320	320	320

Note: Robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1

*Sourc*e: Authors' computation.

Table 7 presents the results of Model 2, which incorporates the share of tourism revenues in the GDP. While the findings of this model largely align with those obtained from Model 1, the impact of tourism revenues exhibits variation across different quantile levels. Specifically, the variable *lntur2*, representing the share of tourism revenues in GDP, positively affects carbon emissions in the 10th quantile. In contrast, it negatively impacts the 75th and 90th quantiles. This study constructs a multi-agent game model under government subsidies and digital platform enabling manufacturing enterprise supply chain, and the logical relationship is shown in Figure 1.

Table 7. MMQREG results for model 2

Quantiles	**(1)**	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**	**(7)**	**(8)**
Variables	**FE-DK**	**location**	**scale**	**qtile_10**	**qtile_25**	**qtile_50**	**qtile_75**	**qtile_90**
lngdppc	0.25***	1.64***	-0.92***	3.05***	2.54***	1.72***	0.754***	0.141
	(0.0671)	(0.262)	(0.113)	(0.294)	(0.311)	(0.296)	(0.282)	(0.311)
lngdppc2	-0.00725	-0.06***	0.045***	-0.13***	-0.10***	-0.06***	-0.0171	0.0132
	(0.0044)	(0.0132)	(0.00567)	(0.0147)	(0.0155)	(0.0148)	(0.0143)	(0.0158)
lntur2	0.03***	-0.0209	-0.06***	0.068***	0.0364	-0.0160	-0.07***	-0.11***
	(0.0071)	(0.0231)	(0.0107)	(0.0244)	(0.0241)	(0.0243)	(0.0275)	(0.0311)
lnglob	0.0452	0.413	0.69***	-0.653**	-0.268	0.355	1.081***	1.544***
	(0.0508)	(0.272)	(0.107)	(0.328)	(0.334)	(0.292)	(0.266)	(0.282)
lnren	-0.18***	-0.23***	0.0214	-0.26***	-0.25***	-0.23***	-0.21***	-0.20***
	(0.0128)	(0.0246)	(0.0133)	(0.0302)	(0.0267)	(0.0247)	(0.0291)	(0.0338)
lnfossil	1.244***	1.180***	0.57***	0.295**	0.61***	1.132***	1.735***	2.119***
	(0.0748)	(0.115)	(0.0379)	(0.131)	(0.155)	(0.142)	(0.105)	(0.0966)
Constant	-5.2***	-14.7***	-0.651	-13.7***	-14.0***	-14.6***	-15.3***	-15.7***
	(0.569)	(1.513)	(0.659)	(1.816)	(1.656)	(1.516)	(1.638)	(1.851)
Obs.	320	320	320	320	320	320	320	320

Note: Robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1

*Sourc*e: Authors’ computation.

The impact of tourism revenues on carbon emissions yielded different results when tourism revenues were expressed as a share of GDP. To check the robustness of these findings, an additional model estimation (model 3) was conducted, where the share of tourism revenues in total exports was used. As shown in the table below, the findings from this model appear to be consistent with those of Model 2. Specifically, in this model, the share of tourism revenues in total exports positively affects carbon emissions at lower quantile levels (10th and 25th). In comparison, a negative effect is observed at higher quantile levels (75th and 90th).

Table 8. MMQREG results for model 3

Quantiles	**(1)**	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**	**(7)**	**(8)**
Variables	**FE-DK**	**location**	**scale**	**qtile_10**	**qtile_25**	**qtile_50**	**qtile_75**	**qtile_90**
lngdppc	0.206**	1.692***	-0.745***	2.84***	2.447***	1.696***	1.00***	0.498*
	(0.0714)	(0.253)	(0.116)	(0.305)	(0.293)	(0.276)	(0.269)	(0.289)
lngdppc2	-0.00503	-0.06***	0.036***	-0.11***	-0.10***	-0.06***	-0.029**	-0.00452
	(0.0046)	(0.0127)	(0.00599)	(0.0155)	(0.0148)	(0.0139)	(0.0137)	(0.0148)
lntur3	0.023***	0.00052	-0.056***	0.088***	0.058*	0.00087	-0.0516*	-0.09***
	(0.0075)	(0.0268)	(0.0117)	(0.0302)	(0.0297)	(0.0280)	(0.0293)	(0.0332)
lnglob	0.105*	0.290	0.485***	-0.460	-0.202	0.287	0.73***	1.06***
	(0.0501)	(0.236)	(0.0860)	(0.292)	(0.287)	(0.246)	(0.219)	(0.233)
lnren	-0.18***	-0.24***	0.0156	-0.27***	-0.26***	-0.24***	-0.23***	-0.22***
	(0.0126)	(0.0268)	(0.0135)	(0.0325)	(0.0292)	(0.0269)	(0.0305)	(0.0353)
lnfossil	1.23***	1.15***	0.552***	0.292**	0.58***	1.14***	1.65***	2.02***
	(0.0709)	(0.114)	(0.0355)	(0.131)	(0.149)	(0.138)	(0.101)	(0.0984)
Constant	-5.16***	-14.3***	-0.436	-13.6***	-13.8***	-14.3***	-14.7***	-15.0***
	(0.580)	(1.490)	(0.664)	(1.874)	(1.692)	(1.491)	(1.559)	(1.763)
Obs.	320	320	320	320	320	320	320	320

Note: Robust standard errors in parentheses. *** $p<0.01$, ** $p<0.05$, * $p<0.1$

*Sourc*e: Authors' computation.

The potential causal relationships among the variables were investigated using the Panel Fisher causality test developed by Emirmahmutoğlu and Köse (2011). In the Emirmahmutoğlu and Köse (2011) causality test, which can be used in the presence of heterogeneous panel data, the Toda-Yamamoto (1995) causality testing procedure, initially developed for time series, is extended to heterogeneous panel data to investigate causal relationships among variables (Ağır & Tıraş, 2018, p. 1563). The Emirmahmutoğlu and Köse panel causality test can be employed when the variables are not stationary in the same order, and there is no cointegration relationship. The null hypothesis states that there is no Granger causality (Topallı, 2015, p. 280).

When the Panel Fisher test statistics presented in Table 9 are examined, it is observed that the null hypothesis is rejected only for the causality running from the *lntur3* variable to the *lnco2* variable. Therefore, in the group of countries under consideration, a unidirectional causality exists from the share of tourism revenues in total exports to carbon emissions.

Table 9. Emirmahmutoğlu and Köse (2011) panel causality test

Direction of Causality	Panel Fisher test statistics	Bootstrap p-value
lntur1→lnco2	100.213	0.963
lnco2→ lntur1	60.281	1.000
lntur2→lnco2	82.610	0.990
lnco2→ lntur2	130.181	0.564
lntur3→lnco2	278.883	0.006
lnco2→ lntur3	103.260	0.986
lngdppc→lnco2	129.419	0.867
lnco2→ lngdppc	301.945	0.520
lnfossil→lnco2	67.161	0.821
lnco2→ lnfossil	166.753	0.397
lnren→lnco2	52.954	1.000
lnco2→ lnren	143.612	0.995
lnglob→lnco2	142.745	0.999
lnco2→ lnglob	94.168	0.999

Note: The lag length and the maximum order of cointegration were set to 2. The Akaike Information Criterion (AIC) was used to determine the optimal lag length.

Source: Authors' computation.

4. Results and discussion

The findings obtained using different representations of tourism revenues in the study demonstrate that the definition of the variable plays a decisive role in the results. The similarity of the results obtained from estimations using the share of tourism revenues in GDP and exports suggests that these two indicators reflect the relative importance of tourism in the economic structure of countries and its impact on carbon emissions. In both cases, the positive effect of tourism revenues on lower carbon emissions indicates that tourism tends to grow alongside high-carbon-intensive sectors such as transportation and accommodation during the early stages of economic development. In contrast, the negative effect of tourism revenues on emissions at higher emission levels points to the possibility that, beyond a certain level of development, the environmental impacts of tourism can be mitigated, signaling that economic contribution and environmental sustainability can be achieved simultaneously. This also highlights the dual nature of the tourism sector, shaped by a balance between economic benefits and environmental costs, and reveals the heterogeneity of this relationship depending on the level of carbon emissions. These findings support the need for differentiated policy approaches based on a country's carbon emission profile (Paramati et al., 2017; Azam et al., 2018). A well-organised tourism sector can contribute to environmental preservation by adopting eco-friendly transportation systems and sustainable technologies. Moreover, a structural shift from carbon-intensive sectors such as agriculture and industry toward the services sector, including tourism, may help reduce overall carbon emissions (Wei and Ullah, 2022, p. 36277).

Further understanding of the heterogeneous nature of the tourism-environment relationship can be gained from the quantile estimation results. The relationship reverses at higher emission levels, indicating that the environmental effects of tourism development depend on the emission profile and structural features of the countries under consideration, although the growth of tourism revenues seems to increase carbon emissions at lower quantiles. This pattern suggests that the impact of tourism development on the environment varies across economies. Rather, as the economic structure, technological capability, and environmental governance change, so does its environmental impact. Growing tourism may initially lead to higher energy consumption in economies with comparatively lower emissions levels, driven by increased mobility, infrastructure development, and demand for hospitality and transportation services. However, the adoption of greener technologies and more economical energy use may progressively lessen the environmental impact of tourism activities as the industry develops and environmental consciousness rises.

The consistency seen across various tourism revenue measures supports the robustness of these findings. The general pattern is essentially the same whether tourism revenue is expressed as a percentage of GDP or of total exports, indicating that tourism's relative importance within the national economy is a crucial factor in determining its environmental implications. The idea that tourism should be assessed as a structural element of economic transformation rather than merely as a means of strengthening a sectoral activity. Understanding tourism's environmental effects depends more on how it interacts with energy use, transportation networks, and environmental regulations as it becomes more integrated into national production and trade systems.

This discussion is further enhanced by the causality analysis, which shows a unidirectional causal relationship between carbon emissions and the percentage of tourism revenues in total exports. This result suggests that shifts in the economic importance of tourism may directly affect environmental outcomes in the nations under consideration. In other words, tourism growth should be seen as both a potential driver of environmental change and a result of economic expansion. The presence of this causal relationship underscores the importance of including environmental factors in tourism development plans, especially in nations where tourism accounts for a significant share of export earnings.

From a policy standpoint, these results imply that environmental regulations for tourism should be tailored to each nation's unique emission profile. Policymakers may need to prioritise investments in energy-efficient transportation systems, sustainable lodging options, and renewable energy use in tourism infrastructure in nations at lower emission quantiles where tourism growth appears to increase carbon emissions. On the other hand, nations with higher emissions might benefit from laws that support eco-friendly travel, foster technological advancement in the hospitality sector, and tighten environmental regulations in tourism-related industries. These steps could guarantee that tourism development promotes both long-term environmental sustainability and economic growth.

Overall, the empirical evidence presented in this study highlights the complex and context-dependent nature of the tourism–environment nexus. Tourism development can simultaneously generate economic benefits and environmental pressures, and the balance between these outcomes depends largely on structural conditions, technological progress, and the effectiveness of environmental policies. Understanding these heterogeneous dynamics is, therefore, essential for designing tourism strategies that align economic development with environmental sustainability goals.

Despite the insights provided, several limitations should be acknowledged. The analysis is based on aggregate country-level data, which may conceal regional differences in tourism development and environmental impacts within countries. In addition, the study focuses on carbon emissions as the primary environmental indicator. In contrast, other measures such as ecological footprint or energy intensity could provide complementary perspectives on the environmental consequences of tourism expansion. Future research may therefore extend this framework by incorporating alternative environmental indicators, examining tourism–environment interactions at the regional or destination level, and exploring the role of institutional quality, environmental regulation, and technological innovation in shaping the environmental effects of tourism development.

5. Conclusions

This study explores the heterogeneous environmental consequences of tourism revenues across a panel of countries with the highest tourism income levels from 2005 to 2020. Utilising the Method of Moments Quantile Regression (MMQREG) and reinforcing robustness through the FE-DK estimator, the analysis provides a nuanced understanding of how tourism's structure and economic role influence environmental outcomes. A salient contribution of the study lies in its multidimensional approach to defining tourism revenues – by their nominal value, share in GDP, and share in exports – which enables a comprehensive structural interpretation of tourism's environmental impact across varying economic contexts.

The empirical findings highlight that tourism revenues exert asymmetric effects on carbon emissions contingent on a country's position along the emissions distribution. In particular, for countries situated in the lower quantiles of carbon emissions – predominantly emerging economies – the nominal value of tourism revenues is positively associated with environmental degradation. This is likely due to the expansion of carbon-intensive sectors, such as transport and hospitality, driven by rising tourism demand in these economies, where environmental regulations may be less stringent or poorly enforced.

Conversely, in countries located at the upper quantiles of the emissions distribution – typically more advanced or structurally mature economies – tourism revenues, when measured as a share of GDP or exports, exhibit a negative and statistically significant relationship with carbon emissions. These findings suggest that in such economies, the tourism sector adopts environmentally sustainable practices, including deploying clean technologies, integrating green innovations, and complying with more rigorous environmental standards. This shift reflects a decoupling of tourism-driven economic growth from environmental degradation.

Additionally, the analysis confirms the Environmental Kuznets Curve (EKC) hypothesis by documenting an inverted-U-shaped relationship between per capita income and carbon emissions. This implies that economic development initially aggravates environmental pressures, but once a certain income threshold is surpassed, further growth is associated with improvements in environmental quality. The findings resonate with previous research by Faisal and Ebrahimi-Salari (2023) and Khan and Hassan (2024), emphasising the critical roles of institutional quality and technological progress in achieving sustainable growth trajectories.

The causality analysis, conducted through the heterogeneous panel causality test of Emirmahmutoğlu and Köse (2011), reveals a significant unidirectional causal relationship from tourism revenues (as a share of exports) to carbon emissions. This result affirms that the influence of tourism on environmental outcomes is not merely correlative but structural, underscoring tourism’s potential as a key determinant in a country’s environmental performance when deeply embedded within its trade structure.

These findings give rise to several policy recommendations. First, environmental sustainability must be mainstreamed into tourism trade strategies in economies where tourism is a major contributor to export revenues. This includes the implementation of eco-certification schemes, promoting energy-efficient transportation systems, and public investment in environmentally sustainable tourism infrastructure. Second, considering the identified causality, national tourism development policies must align with climate change mitigation targets. This can be achieved through the adoption of carbon budgeting frameworks, the establishment of emission thresholds, and the provision of incentives for innovation in green technologies. Third, comprehensive environmental regulations must accompany trade and liberalisation to prevent tourism-driven environmental externalities, particularly in open economies. The strategic coordination of trade, environmental, and tourism policies will be essential to balance economic gains with ecological integrity.

In conclusion, this study offers robust empirical evidence that the environmental impact of tourism is conditional, context-dependent, and structurally embedded. It demonstrates that the same economic activity – tourism – can either exacerbate or alleviate environmental pressures depending on a country’s stage of development, emissions profile, and policy framework. These insights call for differentiated, evidence-based tourism strategies that integrate environmental sustainability at their core.

Future research may benefit from extending the analysis to alternative environmental indicators, such as ecological footprint or particulate matter concentrations, to capture a broader spectrum of environmental quality. Furthermore, disaggregating tourism by segment (e.g., eco-tourism vs. mass tourism) may reveal differential environmental effects. Examining the mediating role of institutional quality, environmental governance, and innovation ecosystems may yield more profound insights into how tourism influences environmental sustainability. Lastly, incorporating dynamic or spatial econometric techniques could further illuminate temporal and regional variations in the tourism-environment nexus.

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