Research Note

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Adaptation to technological and environmental shifts in tourism: How AI and green technologies drive stock returns?

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Abstract

This paper explores the asymmetric effect of artificial intelligence, green technology innovation, and energy transition on tourism stocks using the Quantile-on-Quantile method. The findings reveal that AI adversely impacts tourism stocks in the short-run yet substantially improves them in the long-runs. Likewise, green technology and energy transition exhibit initial adverse effects that subsequently become beneficial, underscoring their long-term advantages. The study provides practical implications for tourism companies, hotel managers, and investors regarding the role of artificial intelligence and green innovations in promoting tourism stocks.

Keywords

artificial intelligence, energy transition, green technology, tourism stocks

Introduction

Artificial intelligence (AI) encompasses a diverse range of systems, algorithms, and technologies designed to exhibit intelligent behaviour. It integrates sophisticated technologies and approaches such as machine learning (ML), the Internet of Things (IoT), big data, and intelligent robotics (Knani et al., 2022). AI is becoming more prominent thanks to advances in computational power, the growth of big data, and the evolution of ML techniques. AI can perform difficult operations, including data collection, processing, and analysis which would conventionally necessitate human intellect. These capabilities support a diverse array of intelligent services and activities, greatly

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influencing interactions between service providers and customers, which in turn significantly promotes service delivery, operations, management, and strategies (Buhalis et al., 2019).

Recently, the role of artificial intelligence in reshaping the tourism and hospitality industry has received significant attention in both academic research and practical applications (Assaf et al., 2025; Kocak et al., 2025; Özkan et al., 2025). Over the past 20 years, various ICTs have been utilized to create value, enhance service delivery, and improve travellers' experiences before, during, and after their trips (Ku and Chen, 2024). AI has also facilitated the integration of robotics technologies to enhance client interactions in restaurants and hotels. By providing more personalized and relevant information, AI helps tourists to make better decisions, ultimately contributing to an improved overall tourism experience. The relationship between AI and tourism has been examined within various theoretical frameworks, particularly those tailored to specific AI applications in the tourism and hospitality sectors. AI forecasting methods are commonly used to investigate the link between AI and tourism (Knani et al., 2022). Despite its significant potential, the role of AI in the tourism industry has not been sufficiently examined from a scientific standpoint. The limited existing literature on the AI-tourism nexus predominantly focuses on developing theoretical frameworks, or on case studies based on cross-sectional data (Islam et al., 2024; Solakis et al., 2024). Moreover, there has been little focus on how AI can contribute to the development of a sustainable tourism industry (Işık et al., 2025).

The interaction between AI and tourism, particularly regarding environmental and sociopolitical factors like energy transition, green technology, and geopolitical risk, has received limited scholarly attention (Tunçel et al., 2025). A key research question arises: How do AI, green technology, and energy transition impact tourism stocks? and can they promote sustainable growth? These factors are crucial for the future of tourism, which requires transitioning to eco-friendly alternatives supported by energy-efficient systems and renewable sources. These innovations reduce the carbon footprint and ensure long-term sustainability (Bhattarai et al., 2022). While AI improves efficiency and customer experience, the integration of green technologies and energy transitions enhances their influence on tourism stocks, which is essential for achieving sustainable growth in tourism sector (Söderholm, 2020).

This study aims to address a gap in the literature by examining the impact of AI, green technology, and energy transition on tourism stocks, providing insights into how these factors can promote a more sustainable tourism industry. The theoretical foundation of this research is premised on the Diffusion of Innovation (DOI) theory that originally coined by (Rogers, 1983). The DOI theory is a widely used in most scientific discourse, particularly from the perspective of technology acceptance and the perceived benefits in tourism sector. Empirically, several scholarly studies have utilized the DOI model to investigate the effect of green and smart tourism technologies on tourists' intentions to adopt, perceived value, and the potential net benefits. (Yi Wang et al., 2025) applied the SmartPLS within the DOI model for China. The authors found that the use of smart and green tourism technologies exerts a significant positive impact on the perceived net benefit. Similarly, (Latiff et al., 2021) employed the Diffusion of Innovation model for Malysia and concluded that the relative advantage, usability, compatibility, and trialability have enhanced tourists' intention to utilize smart tourism technology, resulting in a greater perceived net benefit from tourism sector.

Moreover, due to its demand-driven nature, the tourism sector is particularly vulnerable to external shocks including economic crises, policy uncertainties, geopolitical risks, and climate variability (Kocak et al., 2023). Thus, understanding how tourism stock returns respond to geopolitical risk and energy transition is essential for formulating more resilient strategies aimed at enhancing sustainable tourism. Therefore, by utilizing daily data from June 1, 2018, to August 30, 2023, and employing the advanced Quantile-on-Quantile (QOQ) method, this research will analyse the relationships at different quantiles through parametric and nonparametric estimations. This approach will highlight how AI, green technologies, and energy transitions influence tourism stocks, emphasizing their potentials for long-term sustainability and growth.

Methodology

This paper investigates the effects of AI and green technology innovation on tourism stocks using the novel Quantile-on-Quantile (QOQ) method introduced by Sim and Zhou (2015). The utilization of QOQ method is motivated by the fact that this approach has the potential to asymmetrically examines the influence of the quantiles of one variable on the conditional quantiles of another variable using a combination of quantile regression and nonparametric estimation (Tiwari et al., 2019).

The Quantile-on-Quantile approach provides a comprehensive computational framework for analyzing complex interrelationships among the proposed variables; however, quantile crossing, estimation variability, and sensitivity to data characteristics are significant limitations that require greater scrutiny from researchers. The primary assumptions of the QOQ model include the assumption that there is no linear relationship between the variables across all quantiles, as it allows for flexible and asymmetric relationships. Nevertheless, one of the main limitations of this model is the potential for quantile crossing, which may cause inconsistencies in estimated coefficients across quantiles. Additionally, the model's performance is sensitive to data characteristics, such as sample size and the presence of outliers. To address these limitations, various robustness checks were performed, including (such as using alternative estimators, different sample periods, or sensitivity analyses). These robust checks help ensure the reliability and consistency of our results across different model specifications and data variations.

Equation (1) is a nonparametric quantile regression that reveals the impact of quantile of AI and other variables on the quantiles of tourism stock.

$$Tourism_t = \beta^{\theta}(AI_t, ET_t\, GT_t\, GPR_t\,) + u_t^{\theta} \quad (1)$$

From the above equation, *Tourism* indicates the dependent variable at period to proxied by the Travel &Tourism stock index. AI_t, GT_t *and* E*Tt* refer to the artificial intelligence, green technology innovation, and energy transition stock indices, respectively. The AI, GT, and ET indices are sectoral indices constructed by S&P Dow Jones Indices, which track the stock performance of companies primarily involved in artificial intelligence (AI), green technologies (GT), and energy transition (ET) innovations. These indices represent the market performance of firms leading in these sectors, providing a comprehensive measure of the stock value trends in AI, green technologies, and energy transition. The selection of companies within these indices is based on factors such as market size, innovation capacity, and sectoral leadership. This research incorporates geopolitical risk (GPR_t) as the control variable. θ represents the θ^{th} quantile of the conditional distribution of explanatories, while u_t^{θ} denotes the quantile residual term, whose conditional θ^{th} quantile is assumed be zero. β^{θ} (•) is an unknown function given the missing information about the linkage between tourism stock and AI. All data employed in this study were sourced from S&P Dow Jones Indices, with the exception of the geopolitical risk measure, which was obtained from Caldara and Iacoviell (2022).

Results

Table 1 reports the descriptive statistics and unit root test results. According to these results, the series do not follow a normal distribution. The Tourism Index takes higher values across all statistical measures. Both the Tourism Index and the GPR have relatively high standard deviations, indicating that the data exhibits a wide distribution. None of the variables contain a unit root at their level values.

Table 2 presents the results of the BDS test developed by Broock et al. (1996) to determine whether time series data exhibit deterministic behavior. The test examines the null hypothesis that the time series is linear and independent, meaning the dataset is not chaotic. The results indicate that time series exhibits non-linear dynamics at each dimension and shows chaotic characteristics.

The 3D surface graphs illustrate the results of the QOQ regression, depicting the influence of different quantiles of independent variables on various quantiles of the dependent variable. In each graph, the first horizontal axis (X) represents the quantiles of the independent variable, spanning from 0 to 1, while the second horizontal axis (Z) denotes the quantiles of the dependent variable, also ranging from 0 to 1, capturing the progression from low to high quantiles. The vertical axis (Y) in each figure indicates the parameters of the regression corresponding to each combination of quantiles for the dependent and independent variables. In addition, the 3D surface plots from the Quantile-on-Quantile (QOQ) approach illustrate the non-linear/asymmetry trend between the quantiles of dependent and independent variables. In specific, asymmetric relationships between tourism stocks and the explanatory variables (artificial intelligence, green technologies, energy transition and geopolitical risk) are inconsistent and differ across all quantiles (low, medium, or high quantiles). Moreover, the colour bar on the right side of each graph illustrates the range of impact values: blue areas represent lower impact values, while yellow areas indicate higher impact values.

Figure 1 shows the QOQ impact of AI on tourism stock. The lower-left section of the plot depicts the impact of lower quantiles of AI on the lower quantiles of tourism stock. These areas, located toward the higher part of the vertical axis, indicate a negative effect. Conversely, the right side of the plot highlights the influence of higher quantiles of AI, where the effects become strongly positive at higher quantiles (e.g., 100 and 2000). The scale ranges from −200 to 150, suggesting that although artificial intelligence exerts a negative effect at first, it significantly boosts tourism stock at higher levels in the medium and long-term. These trends clearly reveal a nonlinear relationship between artificial intelligence and tourism stocks as the magnitudes and direction differ across quantile distributions. While positive effects predominantly emerge in higher quantiles, the lower quantiles demonstrate adverse impacts.

Figure 2 illustrates the QOQ impact of GT on tourism stocks. In the lower-left section, the plot reveals a negative impact of lower quantiles of GT on the lower quantiles of tourism stock. However,

Table 1. Descriptive statistics.

Variables	Mean	Std. Dev.	Jarque-Bera	DF-GLS	Obs.
Tourism	694.691	109.725	7.571[b]	−2.094[b]	1321
AI	0.025	0.844	1013.321[a]	−2.585[a]	1321
GT	0.034	1.236	532.583[a]	−2.759[a]	1321
ET	0.021	0.770	2781.806[a]	−1.961[b]	1321
GPR	−0.0006	20.881	206.405[a]	−3.362[a]	1321

[a]$p < .01$, [b]$p < .05$.

Table 2. BDS test results.

Variables	m = 2	m = 3	m = 4	m = 5	m = 6
Tourism	0.184[a]	0.313[a]	0.401[a]	0.459[a]	0.498[a]
AI	0.015[a]	0.036[a]	0.051[a]	0.062[a]	0.067[a]
GT	0.010[a]	0.026[a]	0.039[a]	0.049[a]	0.053[a]
ET	0.018[a]	0.042[a]	0.059[a]	0.072[a]	0.079[a]
GPR	0.031[a]	0.048[a]	0.058[a]	0.061[a]	0.059[a]

[a]$p < .01$.

this negative effect diminishes over time, eventually leading to a positive role at higher quantiles of GT (e.g., 500). The scale ranges from −800 to 200, indicating the potential long-term positive benefits of adopting green technology innovations in the tourism sector. Clearly, the nonlinear effect is noticed in the transitions from negative to positive impact across quantile distribution. The impact of green technologies is inconsistent and fluctuate significantly based on the level of adopted technologies. Higher levels of GT adoption typically yield significant benefits in the medium to long term, even though early stages of green innovation may present adaptation costs. Similarly, the QOQ effect of ET on tourism stocks, as depicted in Figure 3, follows comparable nonlinear trends. ET negatively impacts tourism at lower quantiles, but this effect reverses at higher quantiles with varying magnitudes and direction ranging from −200 to 200. When comparing the magnitudes, it can be concluded that GT exhibit more pronounced effects at both higher and lower quantiles, despite the varying scale ranges. In contrast, Figure 4 demonstrates the QOQ effect of GPR on tourism stock. GPR negatively influences tourism at lower quantiles; however, these effects reverse at higher quantiles, albeit with a relatively smaller magnitude, ranging from −10 to 6 on the scale. The non-linear relationship between geopolitical risk and tourism stocks is further demonstrated by

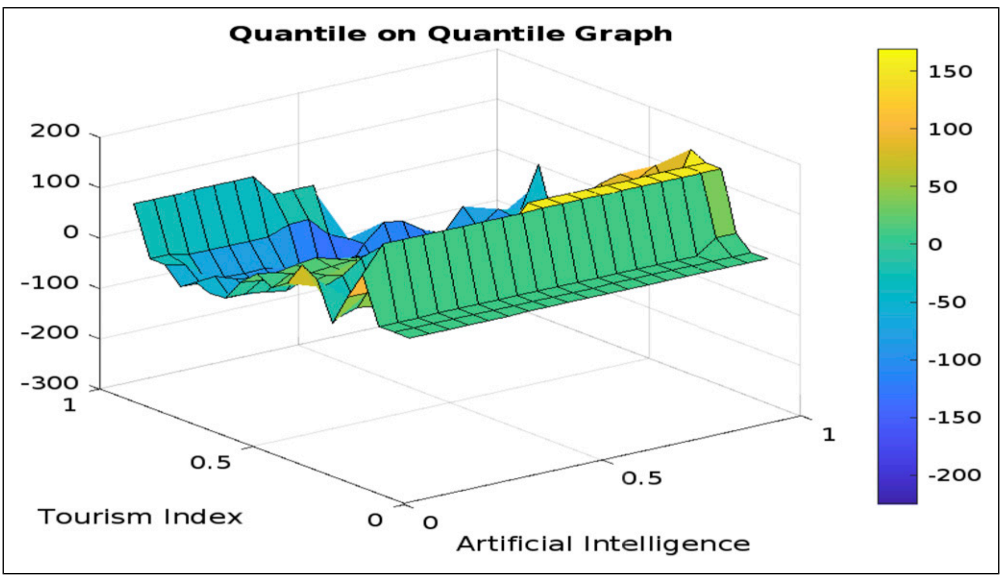

Figure 1. Quantile-on-Quantile impact of AI on tourism stock.

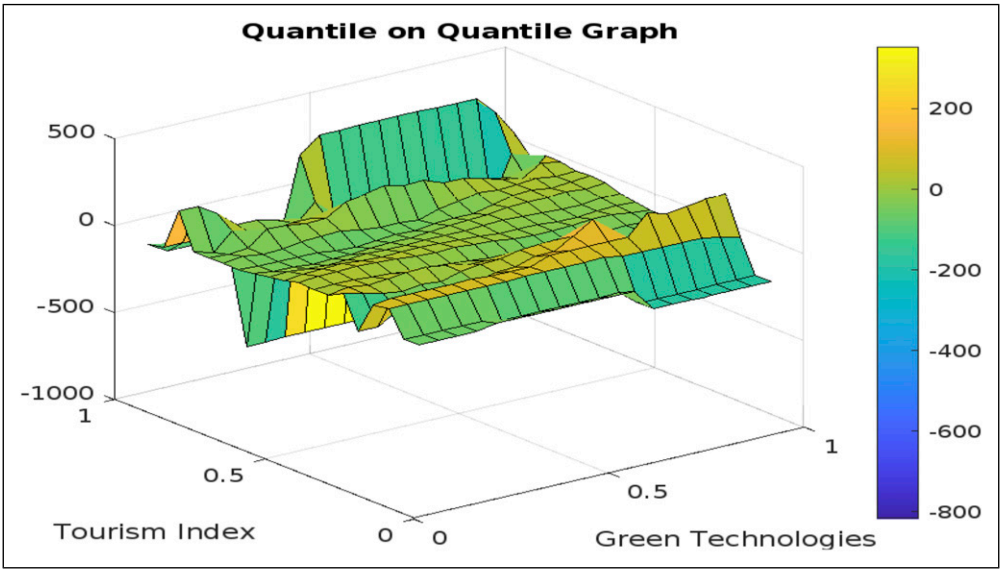

Figure 2. Quantile-on-Quantile impact of green technologies on tourism stock.

this trend. In particular, the negative effects of geopolitical risks are more noticeable at lower quantiles, whereas their effects become less significant or even slightly more favourable at higher market circumstances. Depending on the underlying market conditions, this nonlinearity demonstrates how sensitive tourism stocks are to geopolitical uncertainties.

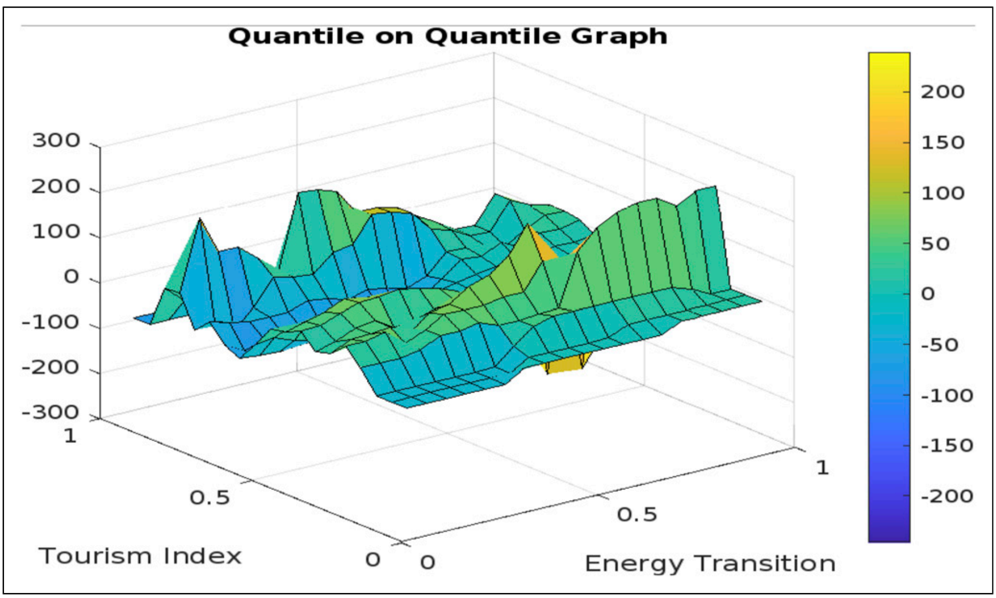

Figure 3. Quantile-on-Quantile impact of energy transition on tourism stock.

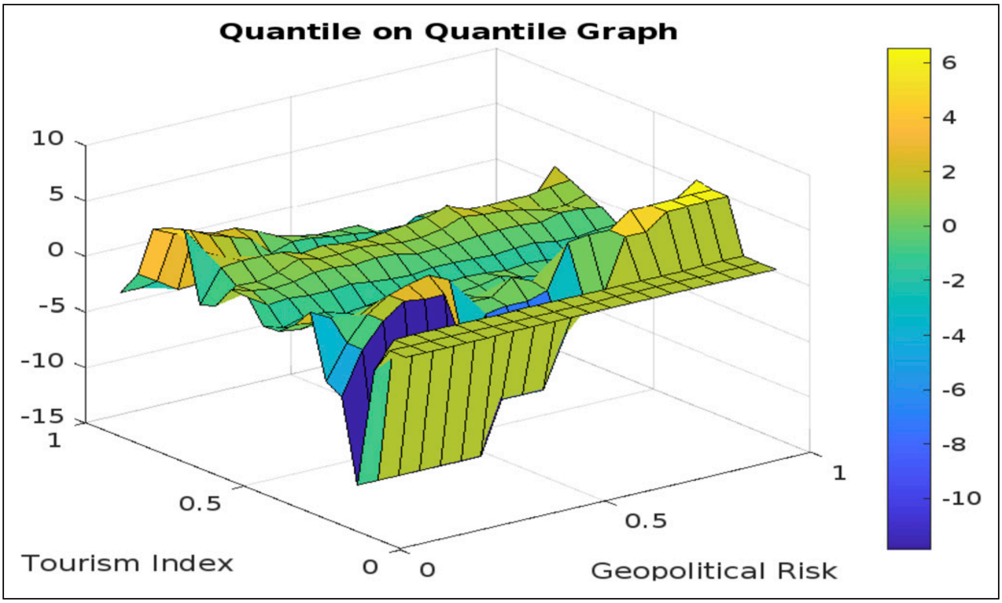

Figure 4. Quantile-on-Quantile impact of geopolitical risk on tourism stock.

Table 3 presents the robustness checks. The validity of the model is tested by comparing the results obtained using an alternative estimator, Robust Least Squares (RLS). This estimator addresses potential issues such as heteroskedasticity (non-constant variance) and outliers in the data. Unlike standard OLS, RLS provides more reliable parameter estimates when the underlying assumptions of linear regression (e.g., constant variance of errors) are violated, ensuring that the results remain valid and stable under various data conditions. Subsequently, for sensitivity analysis, the sample is divided into two subgroups: one before COVID-19 and the other after. According to the results, before COVID-19, AI and GT had no significant effect on tourism, but after COVID-19, these effects became positive and significant. On the other hand, ET negatively impacted tourism before COVID-19, but this effect became insignificant afterward. The findings from the robustness analysis are largely consistent with the key results.

Table 3. Robustness checks.

Variables	Full sample	Pre-COVID-19	Post-COVID
AI	0.356[a] (0.053)	0.0009 (0.0011)	0.038[a] (0.014)
GT	0.092[a] (0.031)	−0.0005 (0.0004)	0.047[b] (0.023)
ET	−0.819[a] (0.060)	−0.001[a] (0.0006)	−0.004 (0.011)
GPR	1.71E-05 (9.60E-05)	2.22E-07 (1.09E-05)	3.87E-05 (0.0001)
R^2	0.19	0.03	0.10
Obs.	1321	446	875

[a]$p < .01$; [b]$p < .05$. Standard errors are reported in parentheses.

Conclusion

This paper explores the impact of AI, green technology, and energy transition on tourism stocks, highlighting their nonlinear effects. In the short term, these factors negatively affect tourism stocks, but over time, especially at higher levels, they lead to positive outcomes. Although artificial intelligence is disruptive at first due to adoption costs, it boosts tourism stocks in the long run by improving efficiency and customer experience. Similarly, green technology and energy transition have short-term negative effects due to high costs, but as they mature, they contribute to sustainable growth and improve the environmental reputation of tourism businesses.

The findings have key implications for policymakers, businesses, and investors. Policymakers should support the adoption of AI, green technologies, and energy transition through incentives and partnerships. Governments must also improve infrastructure to enable the widespread use of sustainable technologies in tourism sector. Addressing geopolitical risks is also crucial by diversifying tourism sources (market diversification strategies) and promoting international cooperation (Lee and Choi, 2023). For businesses, integrating AI and green technologies improves efficiency, customer experience, and environmental reputation, which aligns with global sustainability trends (Liu et al., 2024). These innovations attract environmentally conscious customers and investors, ensuring long-term success.

From an implementation perspective, this study emphasizes the importance of targeted investment incentives and updated regulatory frameworks to support sustainable tourism. Policymakers are encouraged to facilitate the adoption of green technologies and artificial intelligence through financial support mechanisms such as subsidies and tax incentives. Additionally, regulatory measures that promote responsible investment and environmental risk assessments can enhance the sustainability of tourism finance. Managers and investors should consider integrating AI and green innovations into their strategies to balance short-term challenges with long-term benefits. These recommendations aim to guide stakeholders in aligning innovation with financial and regulatory priorities to support a sustainable future for tourism.

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