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Research Article

Empirical Evidence on the Synergistic Development of Informatization, Technological Progress, and the Tourism Industry

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ABSTRACT

Background: In the context of the deep integration of the tourism industry with informatization and technological progress, exploring the mutual influences and dynamic interactions among tourism development, technological progress, and informatization holds significant value for achieving low-carbon sustainable development goals. Methods: Based on provincial statistical data from China between 2008 and 2020, this study employs a panel vector autoregression (PVAR) model to analyze the interactions, characteristics, and trends among informatization, technological progress, and tourism industry development. Results: First, there exists a complex dynamic interaction mechanism among informatization, technological progress, and tourism development. Informatization significantly promotes technological progress and tourism development, while technological progress provides technical support for both informatization and tourism. However, the direct impact of tourism on informatization is relatively limited, with a more pronounced effect on technological progress. Second, impulse response analysis reveals the dynamic adjustment paths among variables: tourism development responds strongly to shocks from informatization and technological progress in the initial stages, followed by gradual attenuation and stabilization. Similarly, informatization shows a strong initial response to shocks from technological progress, which then gradually diminishes and stabilizes. When responding to shocks from tourism, informatization exhibits an inverted U-shaped curve, first rising and then declining. Technological progress also demonstrates an inverted U-shaped curve in response to shocks from tourism and informatization. Third, variance decomposition shows that in the early stages, the fluctuations of system variables are primarily self-explanatory, while dynamic interactions among variables emerge and stabilize over the long term. This study provides policy insights for governments and industry stakeholders on enhancing tourism development, informatization, and technologicalprogress under the framework of sustainable development.

Keywords: Informatization; Technological progress; Tourism industry; Panel vector auto-regression; Pulse response; Sustainable development.

INTRODUCTION

The economic development driven by industrial civilization, while generating unprecedented material abundance, also led to severe challenges, including resource depletion, environmental pollution, and ecological degradation. These pressing issues have ultimately compelled societies to confront the limits of industrialization and the sustainability of economic and social development. This has sparked profound reflection: Can the developmental paradigm of industrial civilization continue indefinitely? Furthermore, the global spread of the COVID-19 pandemic has exacerbated imbalances, inconsistencies, and unsustainable contradictions. To enhance human well-being, nations worldwide are contemplating which principles can guide and coordinate future growth. Against this backdrop, China has introduced a comprehensive framework for building an ecological civilization. Broadly defined, ecological civilization encompasses not only values that emphasize respect for nature and harmonious coexistence with the natural world but also the production models, economic foundations, and institutional systems shaped by these values. Together, these elements form a unique social and civilizational paradigm. The Chinese government, in

its latest report, has articulated the essence of Chinese-style modernization: a modernization characterized by harmony between humanity and nature. Under the principle of preserving nature, China has set ambitious goals to peak carbon dioxide emissions by 2030 and achieve carbon neutrality before 2060. Chinese modernization represents a green modernization, a sustainable modernization, and one that integrates ecological civilization into overall development.

The tourism industry constitutes an integral part of the green economy. Due to its significant scale, the tourism industry contributes substantially to local economic benefits and provides numerous employment opportunities. Nearly all countries and regions worldwide have established tourism and hospitality sectors. Globally, cumulative annual tourist traffic exceeds 10 billion person trips. In 2023, the tourism industry accounted for 9.1% of global GDP, approximately USD 9.9 trillion.

Leveraging its vast natural environment, rich biodiversity, and diverse tourism landscapes, China's tourism industry has embraced modern scientific and technological advancements to stimulate new drivers of industrial growth and establish a new development paradigm. It serves as an integral part of economic development within the framework of an ecological civilization. And it has become a crucial means of improving people's livelihoods, enhancing living environments, increasing public well-being, and meeting the demand for a better life. At the same time, tourism development emphasizes harmonious integration with economic, social, environmental, and resource systems. Due to its sustained multiplier effects, the tourism industry has a broad economic scope. It not only reduces the divide between urban and rural areas but also facilitates resource allocation across the primary, secondary, and tertiary sectors.

With the advent of the metaverse, virtual reality (VR) technology, augmented reality (AR) technology, holographic projection, virtual simulation, immersive technologies, and the wave of a new technological revolution and industrial transformation, the informatization, characterized by high innovation, strong penetration, and extensive coverage, is profoundly shaping the development of the tourism industry. It has gradually become a key driver of high-quality development in the tourism sector. Previous studies on informatization and the tourism industry have rarely focused directly on the modern tourism system. Instead, they primarily explore the relationship and mechanisms of influence between informatization and tourism development. Research indicates that the development of informatization fundamentally reshapes the underlying logic of tourism development. Traditional collaboration models in the tourism industry have evolved, placing greater emphasis on meeting the demands of tourism consumers. Furthermore, informatization have enhanced the efficiency of the tourism industry, improved corporate operational performance and capabilities, and optimized the structure of the tourism sector. The informatization, underpinned by data elements and digital technologies, promotes tourism development through various pathways, including directly advancing regional economic growth, enhancing technological progress, reducing operational costs, stimulating market vitality, and improving public services. Unlike the production tools and methods of the industrial civilization era, the production factors and methods of the informatization era align with the demands of contemporary development, characterized by high efficiency, low pollution, and sustainability. Therefore, this study aims to explore the interaction and influence mechanisms between the tourism industry, technological progress and informatisation.

LITERATURE REVIEW

2.1. Tourism Industry Development and Informatization

Broadly defined, informatization refers to the historical process of fully utilizing information technology, developing and leveraging information resources, facilitating information exchange and knowledge sharing, improving the quality of economic growth, and driving the transformation of economic and social development. Similar to industrialization, informatization fundamentally signifies a new historical stage following industrialization. Informatization is profoundly transforming the modes of production, lifestyles, and governance in human society, exerting significant impacts on the restructuring and development of tourism industry elements [Bec A et al 2021, Zhou X and Chen W 2021]. Particularly in recent years, as the level of informatization within industries has increased and the use of information technology has become more widespread, related academic research has shown an upward trend.

Existing research can be categorized into three main areas. The first area focuses on the impact mechanisms of informatization in fostering new forms. Studies have explored the application of information technology in cultural heritage tourism [Li J et al 2024], intangible cultural heritage tourism [Li H and Ito H. Visitor 2023], and the technological empowerment of museum tourism [He Z et al 2018]. Additionally, research has examined the emergence of virtual tourism [Sun T et al 2024, Loureiro SMC et al 2020], the role of augmented reality in enhancing tourism products [Innocente C et al 2023, O'dwyer N et al 2021], and the use of artificial intelligence and service robots in delivering tourism services [Ali F et al 2024, Rong A et al 2025], all of which have significantly enriched the tourism experience for travelers. The second area examined the impact and mechanisms of informatization on improving the economic efficiency of the tourism industry. A study indicates that the development of informatization during the COVID-19 pandemic facilitated the integration of China's cultural and tourism industries [Wang H et al 2023]. Moreover, the development of the digital economy in various countries and regions has promoted the growth of the tourism industry by improving institutional quality, enhancing market regulation, and increasing trade liberalization [Zhu F et al 2024, Soylu ÖB et al 2024], as well as improving tourism industry performance through technological advancements in distribution channels [Ali S et al 2024]. The third area focuses on the feedback effects of tourism industry development on the application and advancement of informatization technologies. For instance, tourism activities in scenic areas often lead to challenges in visitor flow management, which in turn drives the adjustment and optimization of information technologies [Huang Y et al 2025]. Similarly, heightened expectations from hotel guests regarding service quality and delivery have spurred advancements in service robot technologies and their applications [Başer MY et al 2024].

2.2 Tourism Industry Development and Technological Progress

China's tourism industry extends far beyond the hospitality sector, it is a comprehensive and multi-sectoral industry. It spans the primary, secondary, and tertiary sectors, encompassing areas such as ecological agriculture leisure, natural resources, hot spring wellness, flora and fauna observation, cultivation of tourism-specific agricultural products, production of tourism souvenirs, cultural and creative product design, manufacturing of tourism equipment and recreational facilities, as well as transportation tools such as scenic area cable cars and shuttle buses. The development of the tourism industry provides numerous rich and practical application scenarios for technological progress, covering the entire spectrum of economic and social activities, including dining, accommodation, transportation, sightseeing, shopping, and entertainment [Ceccacci A et al 2024]. The State Council of China issued the "14th Five-Year Plan," emphasizing the promotion of the sustainable and healthy development of the tourism industry. This initiative aims to enhance the role of tourism in advancing the ecological economy and meeting the public's aspirations for a better life, underscoring its significant importance. The plan also highlights the critical role of technological progress in driving tourism development, advocating for the implementation of advanced applications and innovations in areas. Through these advancements, informatization has gradually become a new driving force for tourism industry growth, fostering innovation and transformation in organizational structures, supply methods, industrial models, and consumption patterns within the sector. Moreover, it contributes to the establishment of a new economic development paradigm, centered on domestic circulation while complementing and reinforcing international circulation.

In addition, the tourism industry demonstrates strong industrial linkages. The traction effect of these industrial linkages is particularly evident, as the interconnected growth of these industries further promotes corresponding technological advancements. Romão et al. (2019) employed spatial econometric methods to study 237 European regions, analyzing through empirical results whether and how technological progress impacts tourism development in these regions [Romão J and Nijkamp P 2019]. Yang et al. (2023), using statistical data from 30 provincial administrative regions in mainland China between 2007 and 2019, applied panel vector autoregression (PVAR) and Monte Carlo simulation methods to calculate the interactive relationship between tourism development and technological progress in China [Yang W et al 2022]. Gössling et al. (2019) explored how the emergence and empowerment of information technologies (ICT), among others, provided critical support for the proliferation and development of new P2P in the sharing accommodation sector [Gössling S and Michael Hall C 2019]. Technological progress can stimulate tourism development, foster new business models and product formats, and, through these innovations, enhance tourism consumption, thereby advancing the tourism economy. On one hand, compared with traditional technological progress, tourism-related technological advancements place greater emphasis on sustainable technology. These advancements aim to develop toward technology empowerment and sustainability

[Yang W et al 2022, Wang L et al 2024]. On the other hand, from a long-term perspective, technological progress promotes tourism development. However, in practice, due to high costs, lengthy cycles, and challenges in the commercialization of outcomes, the impact of technological progress on tourism development varies across regions and periods, exhibiting inconsistencies and asynchronies [Lu X et al 2024]. Additionally, in certain regions, technological progress may exert a crowding-out effect on tourism industry development [Zhu F et al 2024].

2.3 Technological Progress and Informatization

Informatization and technological progress share a complex and dialectical relationship, making it difficult to grasp their full scope from the perspective of a single industry. Consequently, some scholars have analyzed this relationship from the angle of internal innovation. Against the backdrop of rapid advancements in information technology, the informatization-driven transformation of industries has become an inevitable trend [Zhang P et al 2022, Thomas MJ et al 2021]. Possessing timely, continuous, granular, and comprehensive information structures is a hallmark of enterprise informatization transformation. The diffusion and integration of informatization serve as a critical opportunity for enterprise innovation and transformation [Schäper T et al 2024]. Its strong penetration capability allows informatization to be widely applied across various sectors in production activities and business management, thereby facilitating the informatization transformation and structural optimization of traditional enterprises while driving technological progress [Pesce D, Neirotti P. 2023].

The impact of informatization on technological progress can be categorized into direct and indirect effects. The direct effects: Informatization directly influences technological progress by transforming production methods and operational processes, increasing the informational content of products, and adding new value to meet consumer demands. It resolves market equilibrium issues by providing comprehensive information to both the supply and demand sides, thereby reducing transaction costs. Informatization enhances management efficiency by enabling the accurate and timely acquisition and transmission of information, ultimately improving decision-making efficiency. Furthermore, it addresses the effective transmission of information through the integration, interconnection, and interaction of information technologies. The Indirect Effects: Informatization indirectly promotes technological progress by encouraging enterprises to optimize their combination of production factors and restructure innovative business processes, thus stimulating internal technological advancement potential. It facilitates the efficient and cost-effective acquisition and absorption of external knowledge, improving transactional efficiency among innovation entities and thereby optimizing the external innovation environment. The role of information technology in innovation and product development: Information technology provides enterprises with an open, flexible, and efficient platform for innovation, enabling them to rapidly access market information, customer feedback, and industry trends to adjust product innovation strategies promptly. In the current era of information, enterprises can leverage big data and artificial intelligence technologies to deeply mine and analyze vast amounts of data, uncovering potential market demands and consumer preferences.

Hoffman's theorem highlights that technological progress drive shifts in industrial structures by reshaping production costs, pricing dynamics, and resource allocation patterns. Consequently, technological progress serves as a pivotal mechanism for transforming factor endowment structures and facilitating industrial optimization and upgrading. Informatization, as a complementary force, enhances production, operational, and managerial technologies by reorganizing and integrating diverse factor resources, including production methods and organizational frameworks. This collaborative effect fosters advancements in production paradigms and generates industrial spillover effects, thereby driving structural improvements across production sectors [Li J et al 2024]. The integration of informatization accelerates the accumulation and circulation of knowledge [Shi Y et al 2023], progressively dissolving the barriers between innovation stages. This enables digital products and services to undergo rapid iterations and upgrades while bolstering dynamic capabilities within the innovation process, such as organizational ambidexterity, restructuring proficiency, and adaptability to digital transformation [Lei A et al 2024]. It drives breakthroughs in innovation and fosters sustainable industrial transformation and development [Márton A 2022]. Informatization offers unique advantages through the unlimited replication, sharing, and real-time interconnection of data, significantly reducing data processing and transaction costs while enabling precise resource allocation. This leads to lower expenditures, improved efficiency, and enhanced productivity for enterprises [Eising-Mertsch L et al 2024]. It fundamentally transforms traditional business models, social relationships, and interactions, thereby increasing market concentration at the national level. Specifically, economic systems become more widely shared, circular, and sustainable [Wang D et al 2022]. Moreover, technological progress exhibits

significant spillover effects [Wang D et al 2022], substantially enhancing economic growth capacity, which ensures the advancement of a country's green economy [Zhang W et al 2023].

2.4. Literature Marginal Contribution

Through literature review, it is evident that existing research primarily focuses on the dynamic relationship between tourism and technological progress [Yu M et al 2024] or the synergistic effects between tourism growth and digital transformation [Zhou X and Chen W. 2021, Yu M et al 2024]. Some studies also treat technological progress as a core element, qualitatively analyzing the impact of informatization on innovative models, technological applications, and consumer experiences in tourism. To address these gaps, this study expands from the following aspects: First, it constructs an analytical framework based on the panel vector autoregression (PVAR) model, integrating China's tourism development, technological progress, and informatization into a unified system and treating them as endogenous variables. This approach does not require predefined hypotheses or the distinction between independent and dependent variables, allowing direct exploration of the interrelationships and mechanisms among variables. Additionally, the PVAR model can control for unobservable effects caused by spatial differences, clearly revealing the diffusion mechanisms of external shocks and assessing the impact of random disturbances [Meng Q et al 2024]. Second, the study incorporates multiple indicators, such as industrial foundation, industrial input, and industrial output, into the tourism development variable, and uses the entropy weight method to calculate weights, ensuring the scientific rigor and accuracy of the indicators. Third, considering the multidimensional nature of informatization development, the study comprehensively measures it from three dimensions: informatization infrastructure, industrial foundation, and terminal applications. Finally, this study explores the relationships and mechanisms between tourism development, green technology advancement and information technology development from a bi-directional and dynamic perspective through panel vector autoregressive modelling.

MECHANISM ANALYSIS AND THEORETICAL FRAMEWORK

With the rapid development of digital technologies and internet infrastructure, the modern tourism industry has gradually evolved into an information-intensive sector. The increasing prevalence of new models combining digital mobile payments and "online product purchases" with "offline tourism consumption" signifies a growing level of informatization and the widespread application of informatization across the tourism industry. The widespread application of informatization in the tourism sector has profoundly transformed the operational models and efficiency of the tourism value chain, injecting new momentum into industry development [Shi Y et al 2023, Gu Y et al 2023]. TThe role of informatization in promoting technological progress in tourism is mainly as follows: Firstly, informatization has spurred diversified innovation in tourism products and business models. The deep integration of digital technologies with the tourism industry has given rise to new cultural and tourism scenarios, such as immersive entertainment, smart guided tours, virtual tourism, digital twin heritage sites, digital museums, and virtual exhibitions [Feng M et al 2023, Wang Z et al 2024]. These innovations have not only enriched the tourism product ecosystem but also accelerated technological advancements, driving the high-quality development of the tourism industry [Yang W et al 2022]. Secondly, the integration of informatization significantly strengthens the tourism sector's capabilities in marketing, management, and distribution. The Internet, as a pivotal marketing platform, facilitates direct engagement between tourism service providers and consumers. It provides substantial technological benefits, such as lowering promotional expenses, enhancing resource efficiency, boosting revenue streams, building comprehensive databases, and fostering long-term customer relationships. By improving the precision of marketing strategies, informatization stimulates consumer demand and significantly advances technological progress within the tourism industry. Third, informatization alters and intensifies the competitive environment in the market, forcing the tourism industry to transform and upgrade. The emergence of enterprises equipped with big data resources and superior capabilities in product development, technology, or management intensifies competition within regional tourism markets. On one hand, established firms leverage technological innovations to bolster their competitive edge and ensure sustainability. On the other hand, heightened competition encourages capital to flow toward tourism enterprises that prioritize innovation, thereby fostering technological advancements in regional tourism sectors. In a broader context, the tourism industry acts as a vital link between secondary and tertiary industrial clusters across the nation, generating substantial spillover effects across multiple sectors. It not only propels production and manufacturing in the secondary sector but also spurs growth in leisure products, retail, and service industries within the tertiary sector. As modern tourism activities become more frequent and consumer demands continue to evolve, the industry's ability to stimulate interconnected sectors has grown

increasingly pronounced, driving technological progress across various fields [Lei A et al 2024]. Building on this analysis, this study delineates the interconnections among the tourism industry, technological progress, and informatization, presenting a theoretical framework illustrated in Figure 1.

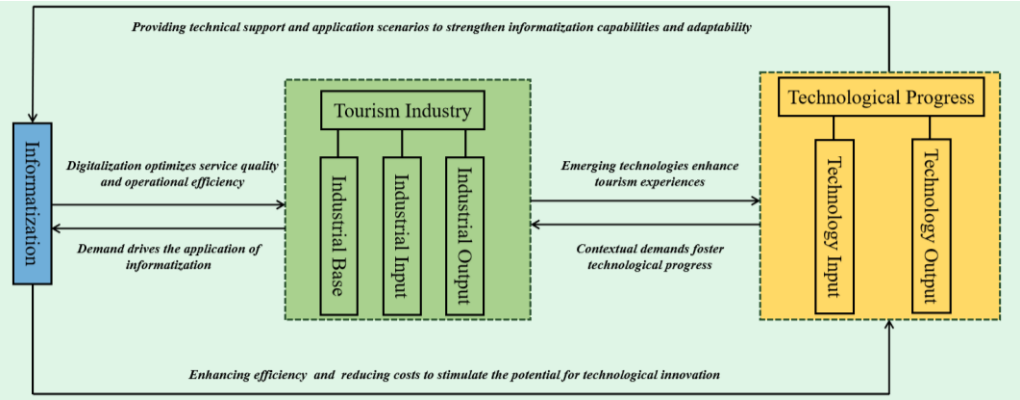

Figure 1. Theoretical framework diagram.

RESEARCH METHOD, VARIABLE SELECTION, AND DATA SOURCES

4.1 Research Method

This study employs a PVAR model based on panel data from 30 provinces and municipalities (including autonomous regions and directly governed cities) in China from 2008 to 2020 to analyze the dynamic relationships among tourism industry development, technological progress, and informatization. The research model is specified as follows:

$$y_{it} = \alpha_i + \gamma_t + \beta_1 y_{i,t-1} + \beta_2 y_{i,t-2} + \ldots + \beta_n y_{i,t-n} + \mu_{it} \quad (1)$$

Where yit = (Tour, Info, Tech) is a 3-dimensional column vector representing the three variables: tourism industry development, informatization, and technological progress. i denotes the regional variable, t represents the time variable, and n is the selected optimal lag order. β is the regression coefficient matrix, which in this study is a 3x3 square matrix. α_i and γ_t denote individual and time effects, respectively, both of which are 3-dimensional column vectors. μ_{it} represents the random disturbance term.

4.2 Variable Selection

4.2.1. Tourism Industry Development (Tour)

Drawing on prior studies [Lin F et al 2023, Wang Y and Fu L 2023], this research utilizes the entropy weight method to evaluate the development of the tourism industry across three dimensions: industrial foundation, industrial input, and industrial output (Table 1). The industrial foundation includes the number of A-rated scenic spots, travel agencies, and star-rated hotels. Industrial input includes the number of employees in travel agencies, star-rated hotels, and scenic spots, as well as fixed asset investment in the accommodation and catering sectors. Industrial output is represented by total tourism revenue.

Table 1. Evaluation Index System for Tourism Industry Development

Primary Indicator	Secondary Indicator	Tertiary Indicator	Indicator Attribute
Tourism Industry Development	Industrial Base	A-rated scenic spots	+
		Travel agencies	+
		Star-rated hotels	+
	Industrial Input	The number of employees in tourism	+
		fixed asset investment in the accommodation and catering sectors	+
	Industrial Output	total tourism revenue	+

4.2.2. Informatization (Info)

Based on previous studies [He L-Y and Chen K-X. 2023, Sun X et al 2023], the entropy weight method is used to measure informatization through long-distance optical cable density, internet penetration rate, and mobile phone penetration rate (Table 2).

Table 2. Evaluation Index System for Informatization

Primary Indicator	Secondary Indicator	Indicator Attribute
Informatization	Long-distance Optical Cable Density	+
	Internet Penetration Rate	+
	Mobile Phone Penetration Rate	+

4.2.3. Technological Progress (Tech)

For the measurement of technological progress indicators, drawing on existing studies [Liu W et al 2021, Fan L-W et al 2021], this study employs the entropy weight method to construct an evaluation index system from both input and output perspectives (Table 3). The input dimension primarily includes R&D expenditure and R&D personnel involved in technological progress activities, while the output dimension consists of the number of patent applications and the regional distribution of technology market outputs (measured by contract value).

Table 3. Evaluation Index System for Technological Progress

Primary Indicator	Secondary Indicator	Tertiary Indicator	Indicator Attribute
Technological Progress	Input	R&D Expenditure	+
		R&D Personnel Involved	+
	Output	The Number of Patent Applications	+
		Regional Distribution of Technology Market Outputs (Contract Value)	+

4.3. Data Sources

This study selects panel data from 30 provinces, autonomous regions, and municipalities in China from 2008 to 2020, forming 390 balanced panel observations. Data for tourism industry development indicators are primarily sourced from the official websites and statistical bulletins of provincial and municipal statistical bureaus, as well as the *China Tourism Statistical Yearbook* (2009–2021). Data for informatization are obtained from the *China Urban Statistical Yearbook* (2009–2021), while data for technological progress are derived from the *China Science and Technology Statistical Yearbook* (2009–2021). Missing data are filled using linear interpolation. The entropy weight method is employed to measure the indicators of tourism industry development, informatization, and technological progress for the 30 provinces, autonomous regions, and municipalities in China from 2008 to 2020.

EMPIRICAL ANALYSIS

5.1. Unit Root Test and Selection of Optimal Lag Order

To avoid potential spurious regression problems caused by data non-stationarity, this study first conducts panel unit root tests for all variables. For robustness, five types of panel unit root tests are performed: LLC, IPS, HT, ADF-Fisher, and PP-Fisher. The specific results are shown in Table 4. The results of the unit root tests indicate that Tour, Info, and Tech do not entirely pass all five unit root tests, suggesting that the original data are non-stationary. However, their first-order difference variables, Dtour, Dinfo, and Dtech, pass all five tests at the 1% significance level, confirming that the first-differenced data are stationary. Therefore, subsequent analyses are conducted using the first-differenced data.

Table 4. Panel Unit Root Test Results

Variables	LLC	IPS	HT	ADF-Fisher	PP-Fisher
Tour	-9.591***	-3.812***	0.239***	151.562***	67.715
Dtour	-15.425***	-8.211***	-0.103***	240.022***	285.406***
Info	-2.873***	0.308	0.419*	40.434	43.962
Dinfo	-5.711***	-9.071***	-0.183***	110.508***	401.722***
Tech	-4.217***	-1.645**	0.383**	57.241	61.710
Dtech	-6.125***	-8.665***	-0.157***	136.496***	361.644***

Note: "*", "**", and "***" denote significance levels at 10%, 5%, and 1%, respectively. The numbers in the table represent the corresponding test statistics.

This study determines the optimal lag order based on MAIC, MBIC, and MQIC criteria, with the results shown in Table 5. The results in Table 5 indicate that all three criteria—AIC, BIC, and HQIC—suggest that a one-period lag PVAR model should be selected.

Table 5. Selection of Optimal Lag Order

Lag	AIC	BIC	HQIC
1	-14.3697*	-13.1475*	-13.8806*
2	-14.2619	-12.8225	-13.6839
3	-13.8824	-12.1856	-13.1988

Note: "*" is the minimum value under the corresponding guideline, i.e. the recommended lag period.

5.2. Panel Granger Causality Test

This study conducted Granger causality tests on the relationships between the three variables. The test results are presented in Table 6. The findings indicate that, at the 5% significance level, informatization and technological progress are Granger causes of tourism industry development. However, tourism industry development is not a Granger cause of informatization, while technological progress is a Granger cause of informatization. Additionally, both tourism industry development and informatization are Granger causes of technological progress. Overall, the results show that the joint significance of all equations is confirmed at the 1% significance level, indicating that the other variables in each equation collectively have dynamic predictive power for the explained variable in the short term. This finding further supports the validity of the model constructed in this study. In summary, except for the unidirectional Granger causality relationship between Dinfo and Dtour, bidirectional Granger causality relationships exist among the remaining variables at the 5% significance level. This suggests that the short-term causal relationship between tourism industry development and informatization may be established through the pathway of technological progress. The specific short-term and long-term causal relationships require further validation through econometric tools such as GMM estimation and impulse response functions.

Table 6. Panel Granger Causality Test

Dependent Variables	Independent Variable	chi2	df	p
Dtour	Dinfo is not the Granger cause	7.391	1	<0.01
	Dtechis not the Granger cause	11.219	1	<0.01
	None of the variables is the Granger cause	15.955	2	<0.01
Dinfo	Dtouris not the Granger cause	0.028	1	0.868
	Dtechis not the Granger cause	9.639	1	<0.01
	None of the variables is the Granger cause	9.707	2	<0.01
Dtech	Dtouris not the Granger cause	3.837	1	0.050

Dependent Variables	Independent Variable	chi2	df	p
	Dinfois not the Granger cause	4.383	1	0.036
	None of the variables is the Granger cause	9.385	2	<0.01

5.3. Robustness Test

To ensure the reliability of subsequent model estimations, impulse response analyses, and variance decomposition, a robustness test was conducted. This test focused on verifying whether the modulus of the dynamic matrix eigenvalues lies within the unit circle (i.e., less than 1). The results, as illustrated in Figure 2, confirm that all eigenvalues are situated inside the unit circle. This outcome demonstrates the robustness of the PVAR model constructed in this study.

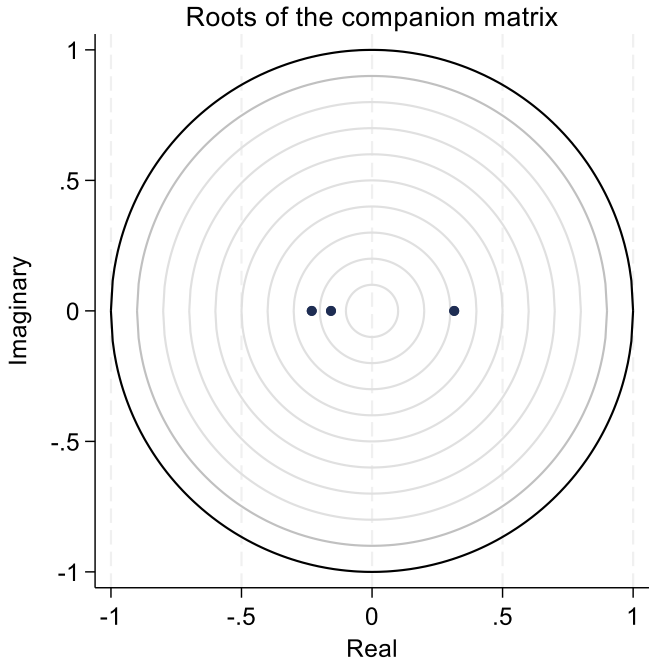

Figure 2. PVAR model robustness test

5.4. PVAR Model Estimation Results

To examine the effects of lagged terms on the variables, this section applies the Generalized Method of Moments (GMM) to estimate the PVAR model. The estimation results are presented in Table 7.

The impact of tourism industry development: The lagged one-period effect of tourism industry development on informatization is not significant (β = -0.006, z = -0.17). This may be because, although tourism development increases the demand for informatization services (e.g., e-ticketing, smart scenic spot management), such demand does not significantly translate into an overall improvement in informatization levels in the short term. Moreover, the development of informatization is more influenced by infrastructure construction and policy support rather than being entirely driven by tourism. The lagged one-period effect of tourism industry development on technological progress is significant (β = 0.076, z = 1.96), indicating that tourism development has a certain driving effect on technological progress. The demand from the tourism industry has promoted the application of technology in tourism scenarios, such as virtual reality (VR), augmented reality (AR) guided tours, and smart scenic spot management systems. As an important market for technology application, the tourism industry provides practical demand and application scenarios for technological research and development.

The impact of informatization: The lagged effect of informatization on tourism development is significant (β = 0.314, z = 2.72), indicating that informatization is a key driver of tourism development. Informatization enhances the efficiency of tourism services, such as online booking platforms, electronic payment systems, and real-time navigation services, making the travel experience more convenient. The development of informatization provides technological support for smart tourism, attracting more tourists and increasing the competitiveness of the tourism

industry. The lagged effect of informatization on technological progress is also significant (β = 0.113, z = 2.09), suggesting that informatization contributes to technological progress to some extent. Informatization optimizes the efficiency of technological research and development by enabling greater data sharing and collaborative innovation capabilities. Additionally, as a carrier for technological diffusion, informatization accelerates the adoption and application of new technologies in socio-economic activities.

The impact of technological progress: The lagged effect of technological progress on tourism development is significant (β = 0.392, z = 3.35), indicating that technological progress is a crucial factor in driving tourism development. Technological advancements significantly enhance the appeal of tourism services through applications such as smart tourism (e.g., intelligent navigation and virtual tourism experiences). Advanced technologies reduce the cost of tourism services (e.g., improved efficiency in transportation and accommodation), thereby increasing tourists' willingness to travel.

Table 7. GMM Estimation Result

Variables	Dtour		Dinfo		Dtech	
	B	z	β	z	β	z
L.Dtour	-0.005	-0.05	-0.006	-0.17	0.076**	1.96
L.Dinfo	0.314***	2.72	-0.026	-0.20	0.113**	2.09
L.Dtech	0.392***	3.35	0.286***	3.10	-0.073	-0.76

5.5. Impulse Response Analysis

The GMM estimation provides a macro-level understanding of the static interactions among variables but falls short of illustrating the dynamic transmission mechanisms and impact pathways between economic variables. To address this, this study employs impulse response functions to further investigate the long-term dynamic relationships among variables. By simulating 1,000 iterations based on the Monte Carlo method, impulse response graphs with a lag of 10 periods are obtained at a 95% confidence interval, as shown in Figure 3.

Analysis of tourism industry development: The tourism variable exhibits a high initial response to its own shocks, but this response diminishes to near zero by the second period. This indicates that the impact of tourism's fluctuations is limited to the short term, highlighting a lack of strong self-sustaining momentum in the tourism industry. Informatization generates a positive shock on tourism, with a strong initial response that gradually diminishes and approaches zero by the third period. This suggests that informatization can significantly promote tourism development in the short term. Similarly, technological progress also has a positive impact on tourism, with a strong initial response that gradually declines to zero by the second period, indicating that technological progress can also promote tourism development in the short term.

Analysis of informatization: The informatization variable shows a strong response to its own shocks, but it quickly stabilizes. This indicates that informatization's fluctuations have a strong short-term self-driving effect, potentially stemming from endogenous diffusion effects related to data infrastructure and service applications. In response to shocks from tourism, informatization exhibits an inverted U-shaped curve, initially increasing and then declining, approaching zero by the third period. In response to shocks from technological progress, informatization shows a strong and significant response, which diminishes and stabilizes by the third period. This suggests that technological progress provides essential technical support for informatization (e.g., communication networks and computational capabilities), thereby fostering its development.

Analysis of technological progress: The technological progress variable exhibits a significant response to its own shocks, but it also quickly stabilizes. This indicates a strong short-term positive feedback effect, reflecting the self-reinforcing mechanism of technological progress. In response to shocks from tourism and informatization, technological progress similarly shows an inverted U-shaped curve, initially increasing and then declining, stabilizing by the third period for tourism shocks and by the second period for informatization shocks.

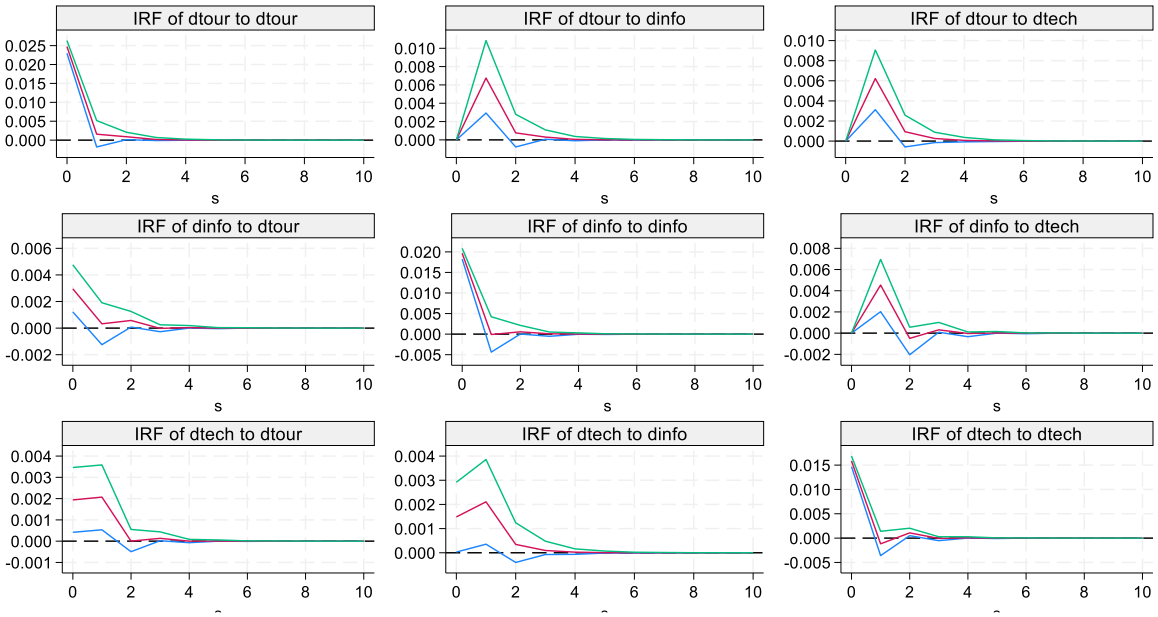

Figure 3. Impulse Response Graph

5.6. Variance Decomposition

To gain a more precise understanding of the mutual influence and long-term interactions among tourism industry development, informatization, and technological progress, this study conducts variance decomposition based on the PVAR model. The results are presented in Table 8.

For fluctuations in tourism industry development, the initial contribution rate of tourism to its fluctuations is 100%, indicating that short-term fluctuations in tourism development are primarily driven by internal factors. The contribution rates of informatization and technological progress are initially zero, suggesting that their short-term impact on tourism fluctuations is insignificant. From the second period onward, the contribution rate of tourism to its fluctuations begins to decline, while the influence of informatization and technological progress gradually emerges, with their transmission effects on tourism fluctuations progressively strengthening. By the fourth period, the contributions of informatization, technological progress, and tourism's internal factors stabilize. For fluctuations in informatization, its contribution rate is the highest in the initial period, approaching 100%, with the remaining contribution coming from tourism industry development. Starting from the second period, the contribution rate of its fluctuations gradually decreases, while the contribution rates of tourism industry development and technological progress progressively increase. Similar to the tourism industry, these contributions stabilize by the fourth period. For fluctuations in technological progress, its contribution rate is initially the highest, followed by tourism industry development and informatization. From the second period onward, the contribution rate of its fluctuations gradually declines, while the contribution rates of tourism development and informatization progressively increase, stabilizing by the third period. Overall, the analysis reveals that, in the initial period, fluctuations in system variables are primarily explained by their dynamics, with minimal influence from other variables, indicating strong short-term independence among variables. In the medium to long term, the contribution rates of other variables gradually increase, reflecting the strengthening of dynamic interactions among variables over time.

Table 8. Variance Decomposition

Response Variable	Shock Variable			
	Forecast Period	dtour	dinfo	dtech
dtour	1	1	0.000	0.000
dinfo	1	0.022	0.978	0.000
dtech	1	0.015	0.009	0.977
dtour	2	0.880	0.065	0.055

dinfo	2	0.021	0.929	0.049
dtech	2	0.030	0.025	0.945
dtour	3	0.878	0.066	0.056
dinfo	3	0.022	0.928	0.050
dtech	3	0.030	0.025	0.945
dtour	4	0.878	0.066	0.056
dinfo	4	0.022	0.928	0.050
dtech	4	0.030	0.025	0.945
dtour	5	0.878	0.066	0.056
dinfo	5	0.022	0.928	0.050
dtech	5	0.030	0.025	0.945
dtour	6	0.878	0.066	0.056
dinfo	6	0.022	0.928	0.050
dtech	6	0.030	0.025	0.945
dtour	7	0.878	0.066	0.056
dinfo	7	0.022	0.928	0.050
dtech	7	0.030	0.025	0.945
dtour	8	0.878	0.066	0.056
dinfo	8	0.022	0.928	0.050
dtech	8	0.030	0.025	0.945
dtour	9	0.878	0.066	0.056
dinfo	9	0.022	0.928	0.050
dtech	9	0.030	0.025	0.945
dtour	10	0.878	0.066	0.056
dinfo	10	0.022	0.928	0.050
dtech	10	0.030	0.025	0.945

CONCLUSION AND DISCUSSION

6.1. Conclusion

This study utilized panel data from 30 provinces and municipalities in mainland China between 2008 and 2020. By employing the entropy weight method, this study accurately measured tourism industry development, informatization, and technological progress, integrating them into an analytical framework. Using the Panel Vector Autoregression (PVAR) model, the study empirically tested the dynamic interactions among tourism industry development, informatization, and technological progress. Monte Carlo simulation methods were applied to analyze the impulse response functions, revealing the dynamic adjustment paths of these variables when subjected to shocks. Variance decomposition methods were employed to quantify the contribution of each variable, clarifying the long-term effects between variables. Furthermore, Granger causality tests were conducted to analyze the causal relationships among the three variables and their underlying mechanisms. The following conclusions were drawn: (1) There is a complex dynamic interaction mechanism among informatization, technological progress, and the tourism industry. Firstly, informatization has a significant positive effect on both tourism development and technological progress. At the same time, technological progress provides robust technical support for the development of both tourism and informatization. From a feedback perspective, the direct impact of tourism on informatization is relatively limited; however, the feedback effect of tourism on technological progress is more

significant. (2) Impulse response analysis reveals the dynamic adjustment pathways among the variables: The tourism industry shows a strong initial response to shocks from informatization and technological progress, which then gradually diminishes and stabilizes. Similarly, informatization exhibits a strong initial response to shocks from technological progress, followed by gradual attenuation and stabilization. In response to shocks from the tourism industry, informatization shows an inverted U-shaped curve, first increasing and then declining. Likewise, technological progress displays an inverted U-shaped curve in response to shocks from both tourism and informatization. (3) Variance decomposition analysis indicates that among the main factors influencing fluctuations in the tourism industry, informatization has the highest contribution rate, followed by technological progress. This highlights the central role of informatization in driving tourism industry growth, while the long-term structural impact of technological progress cannot be overlooked. Similarly, the contribution rate of technological progress to fluctuations in informatization is also significant, further demonstrating the mutually supportive relationship between the two.

6.2. Theoretical Contributions

This study contributes in three main aspects. Firstly, it integrates tourism industry development, technological progress, and informatization into a unified framework, utilizing econometric models to deeply analyze the dynamic relationships among the three. Unlike previous studies that primarily relied on qualitative methods [Huang Y et al 2025, Man S and Gao Z. 2023] or focused solely on the role of informatization in promoting tourism development [Zhu F et al 2024, Ali S et al 2024], this research enriches the field through quantitative analysis. Secondly, the study adopts a more comprehensive set of indicators. It evaluates the tourism industry chain from three dimensions–industrial foundation, input, and output–and employs the entropy method to quantify tourism development, technological progress, and informatization. Existing research often uses single or simplistic metrics to measure informatization [Başer MY et al 2024, Ceccacci A et al 2024] and tends to focus on specific industries [Geng Y et al 2024, Lu Y and Cui B. 2022, Zhang H et al 2024], lacking a multidimensional comprehensive assessment. Lastly, the study employs dynamic panel regression, GMM estimation, Monte Carlo simulation, impulse response analysis, and variance decomposition to explore the connections, interactions, and dynamic characteristics among the three. Previous research has largely overlooked the bridging role of technological progress between tourism development and informatization [Romão J and Nijkamp P 2019].

6.3. Practical Implications

Firstly, regional authorities need to strengthen inter-regional coordination and establish collaborative mechanisms. This includes enhancing macro-policy formulation, promoting technological progress and dissemination, optimizing resource allocation, and fostering complementary advantages. Such cooperation can bridge the gaps and barriers created by digital infrastructure disparities, facilitating the coordinated development of tourism, technological progress, and informatization across regions. Secondly, local governments should expedite the formulation of macro-sustainable development blueprints for informatization. These blueprints should emphasize energy conservation, emission reduction, smart cities, intelligent transportation, and the utilization of green technologies, exploring how the tourism industry can drive informatization development. The level of informatization should, in the future, be incorporated as a core evaluation metric for urban tourism destinations aiming for sustainable development.

Secondly, the tourism industry must continuously improve its technological innovation system and accelerate the construction of informatization infrastructure. The tourism sector should accelerate its convergence with other industries, fostering a synergistic relationship where technological advancements and tourism growth reinforce one another. Digital innovation serves as a pivotal driver for the tourism industry to deepen its integration across sectors and achieve technological breakthroughs. Leveraging digital technology as a key tool is also one of the most effective measures for improving informatization levels across regions. Governments and regulatory authorities in the hospitality industry should enhance the application of digital technologies and artificial intelligence in areas such as upgrading regional tourism industries, enriching consumer experiences and improving service quality for tourists.

6.4. Research Limitations and Future Prospects

Despite conducting extensive statistical tests, this study has two main limitations. First, the COVID-19 pandemic has significantly impacted the global tourism industry and levels of informatization, but this research does not include data from 2021 onwards. Future studies could incorporate more recent data to provide a more comprehensive

analysis of the effects of tourism development and technological progress on informatization. Second, due to limitations in data availability, there is room for improvement in the construction and evaluation of relevant indicators. The tourism industry spans multiple sectors, including dining, accommodation, and transportation, with fragmented data and inconsistent statistical standards, which complicates the research. Moving forward, we plan to leverage information technology and big data mining methods to overcome challenges in data collection and processing, promoting data integration and enhancing the value of research.

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