Author Copy • Author Copy • Author Copy • Author Copy • Author Copy • Author Copy • Author Copy • Author Copy • Author Copy • Author Copy

Pol. J. Environ. Stud. Vol. XX, No. X (XXXX), 1-17
DOI: *10.15244/pjoes/187608* ONLINE PUBLICATION DATE:

Original Research

Does the Digital Economy Promote Tourism Eco-Efficiency? – An Empirical Study Based on Chinese Cities

Wenhao Chen[1], Xiaorong He[1,*], Chaoyue Cai[2]

[1]College of Tourism, Hunan Normal University, Changsha 410081, PR China
[2]College of Tourism and Service Management, Nankai University, Tianjin 300350, PR China

Received: 19 December 2023
Accepted: 18 April 2024

Abstract

With the rapid development of the digital economy, new concepts, forms, and paradigms are being comprehensively integrated into the entire process of constructing human ecological civilizations, and the development of tourism eco-efficiency has ushered in many new opportunities. This paper constructs a mechanistic framework for calculating the impact of the digital economy on tourism eco-efficiency and pushes for empirical research. This paper uses panel data from 275 prefecture-level and above cities in China from 2011 to 2019 as a sample and the benchmark regression model, mediating effect model, and spatial Durbin model to empirically analyze the effect of the digital economy on tourism eco-efficiency after measuring the digital economy and tourism eco-efficiency indexes. The results show that the digital economy has a significant positive effect on tourism eco-efficiency that is more significant in central cities, northeastern cities, and nonurban clusters. Second, the digital economy positively affects tourism eco-efficiency by exerting technological effects and industrial structural adjustments. In addition, the digital economy has a significant positive spatial spillover effect on tourism eco-efficiency. Finally, based on the above findings, this paper proposes specific recommendations for improving tourism eco-efficiency via the digital economy.

Keywords: digital economy, tourism eco-efficiency, spatial Durbin model, China

Introduction

After eco-efficiency was first introduced as an academic concept in 1990 [1], the Organization for Economic Co-operation and Development (OECD) defined eco-efficiency as the efficiency of using ecological and environmental resources to satisfy human needs. The thinking behind it is how to achieve the coordinated development of the economy, resources, and environment. However, during rapid economic development, countries worldwide still focus on resources and the environment as a problem of unbalanced and insufficient development, which has become one of the important factors constraining high-quality development. As the world's second-largest economy, China has declared its determination to achieve "carbon neutrality" and "peak carbon" in the face of ecological and environmental problems during

*e-mail: he1502@126.com

Author Copy • Author Copy • Author Copy • Author Copy • Author Copy • Author Copy • Author Copy • Author Copy • Author Copy • Author Copy

the economic construction process. At the national strategic level, China's *"14th Five-Year Plan"* explicitly points out that accelerating the greening reform of key fields and industries is necessary; thus, promoting greening and decarbonization industries becomes an important goal of China's future economic transformation. In particular, tourism development is closely linked to the regional economy and ecological environment [2]. Tourism can have a positive and significant impact on local employment, local revenue, economic growth, and the tourism chain [3, 4]. However, resource waste, high energy consumption, and high emissions caused by the large-scale movement of people associated with tourism-related activities and the uncontrolled development of the tourism infrastructure should not be overlooked [5]. The key concerns for all walks of life have become balancing the interrelationship between tourism economic growth and ecological environmental protection and realizing the highest economic output with minimum resource consumption, environmental impact, and optimal tourism eco-efficiency.

In the context of the digital economy, digital technology is being comprehensively integrated into the entire process of constructing human ecological civilizations with new concepts, modes, and paradigms and has demonstrated a broad and profound impact on green development [6]. The digital economy is rapidly penetrating various fields, such as agriculture, industry, and services, and is improving the efficiency of industrial development by reducing both transaction costs and resource mismatches [7, 8]. The digital economy can also contribute to improvements in regional ecosystems through technological, structural, and resource allocation effects [9]. Tourism, as a more comprehensive industry, can provide broad space for applying the digital economy, whereas the digital economy provides unlimited possibilities for tourism reform. In China, the government is highly concerned about whether the digital economy can be an important antidote for driving quality and efficiency in the tourism industry. In 2020, China's Ministry of Culture and Tourism issued the Opinions on Deepening "Internet Plus Tourism" and Promoting High-quality Development of Tourism, which proposes accelerating the application of digital technology in the tourism industry to achieve higher quality and efficiency. In 2021, the 14th Five-Year Plan for Tourism Development proposed fully utilizing digital technology to transform the tourism development model from resource-driven to innovation-driven, highlighting the importance of the digital economy in tourism development [10]. Given the requirements of sustainable tourism development, whether the digital economy can help the tourism industry realize the double growth of economic and ecological effects to improve the eco-efficiency of tourism seems a debatable topic.

Previous studies on the digital economy and tourism eco-efficiency have yielded valuable findings; however, gaps remain. (1) Few studies established by previous scholars have linked the digital economy to tourism eco-efficiency or have ignored the enabling role of the digital economy in tourism eco-efficiency. The digital economy is defined as having an important role in economic growth [11] and environmental governance [12], which have become key factors for improving the eco-efficiency of the tourism industry. (2) Scholars have paid more attention to the interaction between the digital economy and eco-efficiency under linear relationships, ignoring spatial spillover effects. The spatiotemporal compression characteristics of the digital economy can eliminate geographic barriers in the information transfer process and have a cross-regional impact on tourism eco-efficiency. Therefore, neglecting spatial factors seriously underestimates the effect of the digital economy. (3) Previous studies have focused primarily on the provincial level in China, with insufficient exploration at the prefecture level and the city level. Therefore, the theoretical analysis framework of digital economy-driven tourism eco-efficiency constructed in this paper focuses on three main issues. First, can the digital economy have an impact on tourism eco-efficiency? Second, is there a mediating effect of the digital economy on tourism eco-efficiency? Finally, is there a spatial spillover effect of the digital economy on tourism eco-efficiency? Answers to these questions help with a response to scholars' concerns and enrich tourism research. In conclusion, by measuring the digital economy and tourism eco-efficiency in 275 prefecture-level and above cities in China from 2011 to 2019, this paper explores the impact of the digital economy on tourism eco-efficiency using benchmark regression models, mediating effect models, and spatial Durbin models. In addition, this paper implements a series of robustness tests to ensure the robustness of the empirical results. First, a theoretical framework for the impact of the digital economy on tourism eco-efficiency is constructed. Second, the relationship between the digital economy and tourism eco-efficiency is empirically examined with China as an example. Finally, in light of China's developmental realities, targeted suggestions are provided for the digital economy to promote tourism eco-efficiency.

The remainder of this paper is organized as follows. The second part is a literature review. Part III includes the theoretical framework analysis. The fourth section explains the variables and describes the econometric model and data sources. In Part V, the empirical results are explained. Finally, in Part VI, the findings are given, and targeted recommendations are made.

Literature Review

Tourism Eco-Efficiency

Ecoefficiency is closely related to the concept of sustainable methods. The World Business Council for Sustainable Development (WBCSD) has defined

Author Copy • Author Copy • Author Copy • Author Copy • Author Copy • Author Copy • Author Copy • Author Copy • Author Copy • Author Copy

eco-efficiency as "the provision of competitively priced goods and services that meet human needs and improve their quality of life, while progressively reducing, to the extent possible, the ecological impacts and resource intensity of a product or service throughout its life cycle to a level at least in line with the Earth's predicted carrying capacity" [13]. Eco-efficiency, as a sustainable analytical tool, is widely used in ecological and economic impact assessments in agriculture, industry, and mining.

With the increasing prominence of tourism ecological problems, the concept of eco-efficiency has been gradually introduced into the field of tourism research and is derived from the concept of tourism eco-efficiency. That is, the two-way fit of tourism ecological environment improvements and tourism economic enhancements minimizes the negative effect of tourism on the environment, maximizing the added value of the tourism economy [14]. Improving tourism eco-efficiency is highly important for sustainable tourism development; therefore, many scholars have focused their research perspectives on the following aspects. First, they have defined the concept of tourism eco-efficiency. Among the established studies, fewer of them explicitly present the concept of tourism eco-efficiency, and most of the definitions in these studies are extensions and expansions of the WBCSD's definition of eco-efficiency. For example, Stefan et al. [15] considered tourism eco-efficiency an important indicator of the proportional relationship between tourism development and environmental impacts. He expressed tourism eco-efficiency in terms of the ratio of carbon dioxide emissions in the tourism process to tourism revenues. Lyn et al. [16] considered tourism eco-efficiency as the ratio of tourism revenue to the tourism ecological footprint, which is calculated by replacing CO2 emissions with the ecological footprint. Xiao suggested that tourism eco-efficiency is reflected in the ratio of greenhouse gas emissions generated during tourism to tourism revenue, indicating a relationship between tourism economic development and its pressure on the ecological environment. Second, tourism eco-efficiency was measured and assessed. Currently, two main approaches are used to measure tourism eco-efficiency. The first is the single-indicator approach, such as in Sabine et al. [17], who choose greenhouse gas emissions and tourism value added to measure the eco-efficiency of Swiss tourism. Bruijn et al. [18] chose to calculate carbon emissions from tourism in relation to tourism revenues. However, since the single-indicator approach does not accurately measure eco-efficiency, many scholars have begun to use the modeling approach. For example, Guo et al. [19] used the EBM-ML model to measure the tourism eco-efficiency of Chinese provinces, and Zhang [20] used the SBM-DEA model to measure and explore the heterogeneity of tourism eco-efficiency in the three regions of Beijing, Tianjin, and Hebei, China. Third, this paper explores the influence mechanism of tourism eco-efficiency and discusses improvement strategies. Scholars have mostly used econometric statistical modeling to analyze the influencing factors. For example, Wu et al. [21] found that an increase in the level of environmental regulation not only had an impact on the tourism eco-efficiency of the province but also had a similar impact on the tourism eco-efficiency of neighboring provinces. Zhang et al. [22] pointed out that new urbanization has a positive effect on tourism eco-efficiency in China, and this effect is more significant in economically developed regions. Castilho et al. [23] found that tourism receipts affect the decline in a country's eco-efficiency but that tourism capital investments and direct tourism employment promote long-term eco-efficiency. These findings provide lessons for the sustainable development of tourism destinations.

Digital Economy

With rapid breakthroughs in mobile communication technology, digital communication technology has been embedded at all levels of the economy and society, and human society has experienced an evolution from the "information economy" to the "Internet economy" to the "digital economy". In 1996, Tapscott et al. [24] first proposed the concept of the digital economy, which is considered an economic system that makes extensive use of Information and communication technologies (ICTs), including information infrastructure and e-commerce transaction models. Subsequently, Negroponte et al. [25] suggested that digitization, informatization, and networking have brought substantial changes to human production and life, resulting in a completely new digital way to exist. In China, the definition of the digital economy originated from the 2016 "G20 Digital Economy Development and Cooperation Initiative". This initiative covers a wide range of economic activities, including the use of digitized information and knowledge as key factors of production, modern information networks as important spaces of activity, and the effective use of information and communications technology as key drivers of the efficiency and optimization of economic structures [26]. Worth recognizing is that the digital economy, with information technology as its core driving force, applies technology to all sectors of the national economy and is constantly integrated with the economy and society [27].

Along with the continued development of the digital economy in the human economy and society, the impact of the digital economy has gradually become a hot spot of academic research. Established studies have shown that the digital economy has a positive impact in terms of both economic [11] and social [28] effects. In recent years, several scholars have begun to pay attention to the environmental effects of the digital economy and have confirmed how the digital economy has a positive impact on the ecological environment from different research perspectives. Asongu [29] investigated the relationship among pollutant emissions, openness

Author Copy • Author Copy • Author Copy • Author Copy • Author Copy • Author Copy • Author Copy • Author Copy • Author Copy • Author Copy

to the outside world, and information technology in Africa and concluded that the application and development of information technology help reduce environmental pollution. Ulucak and Khan [30] used BRICS countries as a research sample and found that the broad application of information technology effectively reduces carbon emissions and that the updating and upgrading of information technology play important roles in improving the environmental quality of BRICS countries. Given the deepening integration of the digital economy with the real economy, some scholars have focused on whether new business forms have environmentally friendly characteristics. Oláh et al. [31] argued that e-commerce prevents unnecessary waste in the manufacturing process by streamlining the product production process, thereby reducing environmental protection costs and improving air quality. Xu et al. [12] noted that the digital economy has spawned numerous new platforms for economic activities in China, which has improved resource allocation efficiency, promoted the sustainable development of the economy, and provided a solid guarantee for saving energy and reducing pollutant emissions.

Specifically, an increasing number of scholars have begun to pay attention to the impact of the digital economy on the tourism industry, and related research has focused mainly on enhancing ICT applications in relation to tourism development or the tourism economy. Adeola et al. [32] used a sample of 40 countries in Africa for their study and found that increased smartphone and internet penetration play an increasingly positive role in the development of tourism in these countries as the number of users increases. Yang [33] demonstrated that Internet use has a positive impact on both the quality and efficiency of tourism development in China. In addition, some scholars have focused on the application of new technologies, such as artificial intelligence [34] and blockchain [35] in the tourism industry, and have used the tourist experience as an entry point.

The Digital Economy and Tourism Eco-Efficiency

In summary, the digital economy can not only promote economic growth but also have a positive effect on environmental improvements. As a result, some scholars have linked the economy to the ecosystem and have explored how the digital economy affects eco-efficiency in regional, urban, and industrial contexts. In an empirical study with China as the case site, Lu et al. [36] explored the impact and spatial effects of the digital economy and industrial eco-efficiency. Yang et al. [37] found that the growth in the digital economy can greatly improve green eco-efficiency, in which environmental legislation plays a useful moderating role. Gui et al. [38] used a panel data regression model and panel vector autoregression (PVAR) model to explore the direct and dynamic effects of the degree of digital economy development on regional eco-efficiency. Liang et al. [39] argued that industrial structure optimization plays a mediating role in the process of enhancing urban eco-efficiency in the digital economy.

In tourism-related research, existing studies have focused more on the impact of digital economy development on tourism economic growth. However, few articles have combined the tourism economy and ecology to explore the impact of the digital economy on tourism eco-efficiency, especially for developing countries such as China. Furthermore, the theoretical framework of the impact of the digital economy on tourism eco-efficiency has not yet been fully developed. Therefore, this paper constructs a theoretical framework for analyzing the effect of the digital economy on tourism eco-efficiency in the context of China and uses it in empirical research. Finally, most scholars have focused on the linear relationship between the digital economy and eco-efficiency; however, investigating whether spatial spillovers exist between the digital economy and tourism eco-efficiency is equally worthwhile. This paper uses 275 prefecture-level and above cities in China as the research samples; measures the digital economy index and tourism eco-efficiency index based on the entropy weight TOPSIS method and the Super-SBM model with undesirable outputs; explores the impact of the digital economy on tourism eco-efficiency using a benchmark regression model, mediating effect model, and spatial Durbin model; and finally put forward suggestions based on the conclusions obtained.

Mechanism Analysis and Theoretical Hypotheses

The new technology, new industry, and new modes derived from the continuous development of the digital economy provide good solutions to the remarkable contradiction between economic growth and environmental protection. Against the background of the new development paradigm, the development of tourism eco-efficiency cannot be separated from the effective assistance offered by the digital economy. This is not only an inevitable requirement for tourism development but also a realistic need for the integration of the digital economy into the real industry. As shown in Fig. 1, the digital economy promotes tourism eco-efficiency in two ways: direct and spillover effects. On the one hand, the digital economy achieves a balance between the growth in the local tourism economy and environmental protection by breaking through the technical dilemmas of the tourism industry, optimizing the industrial structure of tourism destinations, and giving full play to its own resource flow and allocation advantages. On the other hand, from the perspective of space-time compression theory, mobile communication technology, as the core of the digital economy, has greatly compressed the time and space of communication between objects [40]. Spatial spillovers manifested by these supergeographical features, combined

Author Copy • Author Copy • Author Copy • Author Copy • Author Copy • Author Copy • Author Copy • Author Copy • Author Copy • Author Copy

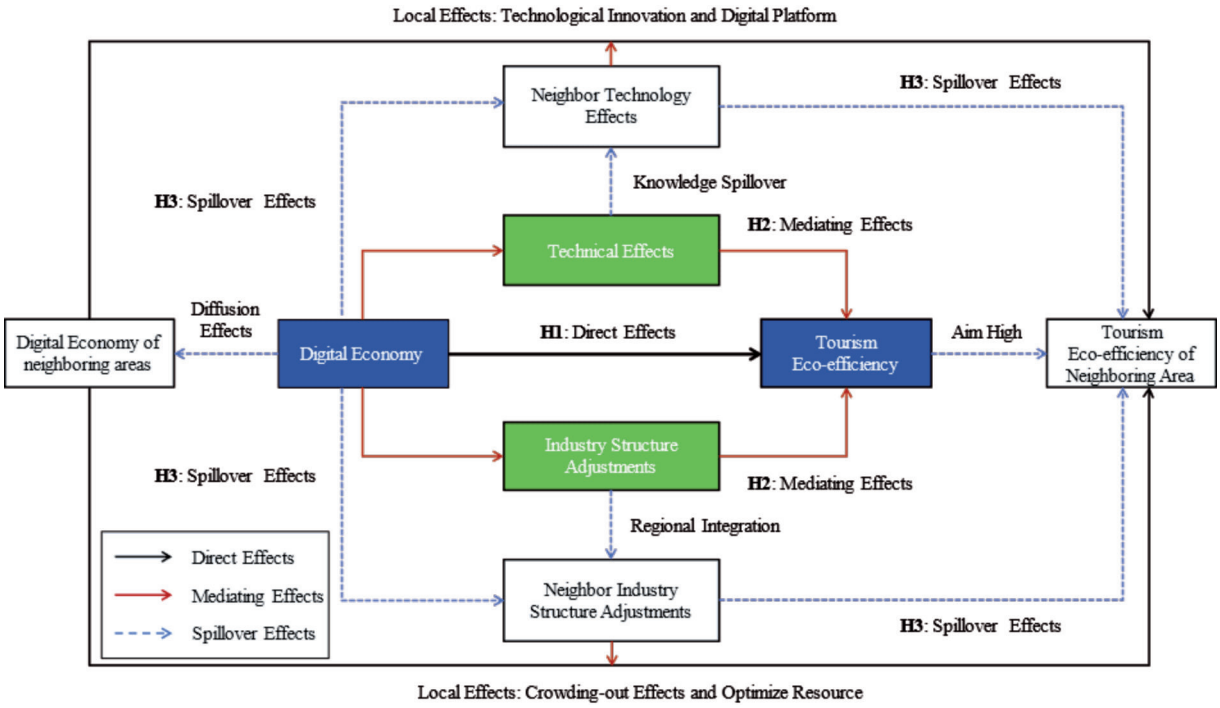

Fig. 1. Mechanism diagram of the impact of the digital economy on tourism eco-efficiency.

with mediating effects from both the knowledge spillover and regional integration perspectives, can have an impact on the eco-efficiency of neighborhood tourism.

Direct Effects of the Digital Economy on Tourism Eco-Efficiency

The digital economy involves broadband networks, data centers, and various digital platforms. The digital economy offers new opportunities to improve tourism eco-efficiency from both the supply and demand sides through its advantages of openness and sharing, spatial ubiquity, and resource integration. On the supply side, based on the theory of resource allocation, to obtain the best economic efficiency with the least possible resource consumption, enterprises are required to accurately grasp the market supply and demand fit. In the non-digital economy environment, market resource elements are fragmented. Project development in the tourism industry inevitably results in resource waste and environmental damage due to the lack of reasonable guidance on supply and demand. In contrast, the digital economy can weaken the limitations of geographic isolation and realize the "virtual integration" of decentralized market resources in the information space [41]. The digital economy also helps the tourism industry enhance the agility of the supply chain while also helping it match supply and demand, optimizing the appropriateness of the flow of resource elements and reducing the environmental pressure brought about by disorderly scale expansion. On the one hand, according to network effect theory and Metcalfe's law, as more resource elements are gathered in the digital economy, the economic value hidden behind them increases exponentially. This process actually creates economies of scale [42]. The economic scale of the digital economy helps the tourism industry create a new mode of production in the information space. In contrast, this approach reduces the strong dependence of the traditional production mode on natural resources and the environment. On the demand side, driven by the concept of sustainable tourism, the dependence of the tourism industry on a good ecological environment encourages tourists to strengthen their awareness of ecological and environmental protection. The digital medium becomes an effective means for creating a feedback mechanism for ecological conservation between the tourism industry and tourists and for promoting the concept of sustainable development [39]. For example, managers use digital media to disseminate the concept of green living to the public. Therefore, hypothesis 1 is formulated.

Hypothesis 1. The digital economy directly drives tourism eco-efficiency.

Mediating Effects of the Digital Economy on Tourism Eco-Efficiency

The development of the digital economy encourages all kinds of derivative industries to continuously push forward and change technology. ICT is the core driving force of the digital economy, and rapid changes in ICT not only drive human society from the information economy to the Internet economy to the digital economy [27] but also the integration and interaction of the national economy with society deepen and become

Author Copy • Author Copy • Author Copy • Author Copy • Author Copy • Author Copy • Author Copy • Author Copy • Author Copy • Author Copy

closer. Compared with the information economy and Internet economy of the past, the digital economy has changed because of the rapid development of digital technologies such as mobile communications and the deepening of its application scenarios. The digital economy exhibits a strong technological effect through interactions with other sectors. In the tourism industry, the digital economy relies on technological effects [9] to promote tourism eco-efficiency. Specifically, resource agglomeration provides a basis for the tourism industry to overcome this technological dilemma. Some tourism enterprises have begun to introduce digital technology and equipment, which are used to enhance the environmental monitoring capacity of tourism destinations, improve the level of waste gas and pollutant management, and optimize the mode of ecological environment management.

On the other hand, technological breakthroughs not only strengthen a destination's ability to manage its ecological environment but also influence the transformation and upgrading of the local industrial structure, thus further improving the destination's tourism eco-efficiency. Specifically, digital technology forces the adjustment and optimization of the original industrial structure through the "crowding out effect", compresses the transformation of enterprises and industries with high energy consumption, guides the flow of resources to efficient and advanced enterprises and industries, and transforms the regional industrial structure to clean and efficient. Thus, digital technology is conducive to realizing the organic unity of economic growth and a good ecological environment and improving the overall tourism ecological efficiency of destinations. In addition, data, as the most crucial production factor of the digital economy, provide new kinetic energy for upgrades to the industrial structure [39]. The digital economy applies data as the associated medium to accelerate the integration and development of the tourism industry with other industries and promotes its development in the direction of high-technology content and environmental friendliness. Therefore, hypothesis 2 is formulated.

Hypothesis 2. The digital economy relies on technological effects and industrial structure adjustments to enhance tourism eco-efficiency.

Spatial Spillover Effects of the Digital Economy on Tourism Eco-Efficiency

The spatial spillover effects of the digital economy [43] promote neighborhood tourism eco-efficiency through the following four paths. First, the digital economy is characterized by openness and transparency. This approach can not only support cross-regional collaboration among tourism enterprises to reduce high financing and transaction costs in an asymmetric information environment but also enhance the efficiency of matching the supply and demand of tourism products to avoid wasting resources due to spatial mismatches [44] and achieve Pareto optimization in the tourism industry. Second, according to the knowledge spillover theory, the development of the digital economy has broadened interregional green knowledge circulation channels [45], improved the accessibility of green information, technology and management concepts, and other resources, and facilitated the dissemination and sharing of green knowledge in the interregional context to realize stronger green knowledge spillover effects and significantly improve the efficiency of the utilization of regional tourism resources and green development ability. Third, from the perspective of regional integration, industrial development and economic activities between neighboring regions exhibit greater closeness. The digital economy promotes local tourism eco-efficiency through industrial restructuring and upgrading and improves the industrial structure of neighboring regions through spatial spillovers, thus promoting tourism eco-efficiency growth. In addition, along with the government's strong emphasis on the digital economy to empower the building of an ecological civilization and sustainable development, this may lead to "aim high" interregional behavior [46]. That is, improving tourism eco-efficiency through the local digital economy inspires neighboring regions to improve their own tourism eco-efficiency through high resource utilization and better green governance. In summary, the four different spillover approaches ultimately rely on the digital economy affecting tourism eco-efficiency through technological effects and industrial restructuring, which is described in detail in the section on direct and mediating effects. Therefore, hypothesis 3 is formulated.

Hypothesis 3. The digital economy can drive tourism eco-efficiency in neighboring areas through spatial spillover effects.

In summary, regarding the direct effects on local tourism eco-efficiency, the digital economy has its own resource allocation advantages to avoid the disorderly development of the tourism industry caused by the spatial mismatch of market resource elements. In addition, the economies of scale of the digital economy help the tourism industry transform its traditional production methods, which are overly dependent on natural resources. In the process by which the digital economy directly affects local tourism eco-efficiency, technological effects, and industrial structure optimization play mediating roles. Both factors provide possibilities for the optimization of resource allocation and economies of scale in the tourism industry through the digital economy. Various paths exist through which the spatial spillover effects of the digital economy occur, such as knowledge spillover, regional industrial restructuring, and "aim high" behavior. However, in the final analysis, these effects are achieved through the stimulation of the resource allocation advantages of the digital economy and, thus, its impact on tourism eco-efficiency.

Author Copy • Author Copy • Author Copy • Author Copy • Author Copy • Author Copy • Author Copy • Author Copy • Author Copy • Author Copy

Variables, Models, and Data

Variables

Explanatory Variables

According to the existing research results [40, 47] and based on data availability, the index system of the digital economy is constructed from the three dimensions of inclusive digital finance, digital industry, and digital infrastructure (Table 1). Inclusive digital finance is an important part of the digital economy and is assessed using three variables: coverage of digital finance, depth of digital finance, and digitalization degree of digital finance [48]. The digital industry supports the digital economy, as measured by the number of people employed in computer services and software and the volume of telecommunications businesses. Digital infrastructure is the basic security of the digital economy and is measured using two variables: the number of Internet users and the number of cell phone subscribers. In addition, to ensure the scientific nature of the research results, extreme value standardization is first used to normalize various indicators, followed by the entropy method to obtain the weights of each indicator. Finally, the entropy-weighted TOPSIS method is used to calculate the index value.

After this paper constructs the index system, this paper adopts the entropy method to obtain the weights of the indicators and further uses the entropy-weighted TOPSIS method to measure the digital economy index (*Dige*).

The first step is to normalize the data. To eliminate the influence of the different dimensions of each indicator on the evaluation results, this paper uses the range method to standardize the original data. Among them, formula (1) calculates the positive indices.

$$\mathrm{X_{ij}} = \frac{\mathrm{x_{ij} - min x_{ij}}}{\mathrm{max x_{ij} - min x_{ij}}} \tag{1}$$

where X_{ij} denotes the normalized value of indicator j of city i, and x_{ij} denotes the original value of indicator j of city i.

The second step is to normalize the data.

$$P_{ij} = Y_{ij} / \sum_{i=1}^{m} Y_{ij} \tag{2}$$

The third step is to calculate the information entropy E_j of indicator j in year t.

$$E_j = -\frac{1}{\ln m} \sum_{t=1}^{m} P_{ij} \ln P_{ij} \tag{3}$$

The fourth step is to calculate the weight W_j of each indicator.

$$W_j = \frac{1 - E_j}{\sum_{j=1}^{n} (1 - E_j)} \tag{4}$$

The fifth step is to calculate the weighting matrix.

$$R = (r_{ij})_{mn}, r_{ij} = w_j x_{ij}$$
$$(i = 1,2,\cdots,m; j = 1,2,\cdots,n) \tag{5}$$

The sixth step is to determine the optimal and the worst solutions.

$$S_j^+ = \max(r_{1j}, r_{2j}, \cdots, r_{nj}), S_j^- = \min(r_{1j}, r_{2j}, \cdots, r_{nj}) \tag{6}$$

The seventh step is to calculate the Euclidean distance between the various schemes and the optimal and the worst solutions.

$$\mathrm{sep}_i^+ \sqrt{\sum_{j=1}^{n} (s_j^+ - r_{ij})^2}, \mathrm{sep}_i^- \sqrt{\sum_{j=1}^{n} (s_j^- - r_{ij})^2} \tag{7}$$

Finally, this paper calculates the evaluation index of the digital economy.

$$C_i = \frac{sep_i^-}{sep_i^+ + sep_i^-} \tag{8}$$

Table 1. The evaluation index system of digitalization development.

Objective Layer	Element Layer	Indicator Layer	Indicator Attribute	Weight
Digital Economy Index (*Dige*)	Inclusive Digital Finance	Coverage of digital finance	Positive	0.1328
		Depth of digital finance	Positive	0.1355
		Digitalization degree of digital finance	Positive	0.1323
	Digital Industry	Number of employees in the information, computer services, and software industries	Positive	0.1622
		Total telecommunications business per capita	Positive	0.1567
	Digital Infrastructure	Number of Internet users per 100 people	Positive	0.1461
		Number of mobile phone users per 100 people	Positive	0.1344

Author Copy • Author Copy • Author Copy • Author Copy • Author Copy • Author Copy • Author Copy • Author Copy • Author Copy • Author Copy

Explained and Control Variables

The core idea of tourism eco-efficiency is to obtain maximum tourism economic benefits with minimum resource inputs and environmental costs by focusing on the relationship between tourism economic development and resource and environmental utilization. This paper draws on the research results of Wang [49], Li [50], and Huang [51], and uses tourism resources, labor, and input capital elements as tourism input indicators. Among them, tourism resources are composed of the sum of the number of star-rated scenic spots and hotels, tourism labor force input is referred to as the number of employees in the tertiary industry, and tourism input capital elements are referred to as the amount of tourism fixed capital investments. The desired output indicator is expressed as gross tourism receipts. Undesired outputs are expressed in terms of pollutant emissions, such as tourism wastewater, waste gas, and smoke and dust. Given the lack of complete tourism-related statistical indicators, tourism fixed capital investments and pollution emission indicators are converted by the share of tourism revenue in GDP. The tourism eco-efficiency index is measured using the Super-SBM model with undesirable outputs.

To improve the accuracy of the results, this paper selects the following five control variables. (1) The level of economic development can optimize the socioeconomic environment and has a significant impact on tourism industry inputs and outputs. Economic density (*ED*) is expressed as the ratio of GDP to urban land area [20]. (2) Urbanization is a transformation process in the socioeconomic structure. Accumulating resources and factors formed during this process can have an impact on the development of the scale of the tourism industry. The urbanization level (*UL*) is expressed as the ratio of the resident nonagricultural population to the total resident population [20]. (3) High-quality labor has advantages in reducing the loss rate of tourism energy resources and the environment, improving the efficiency of production factor allocation in the tourism industry, and enhancing the willingness to adopt advanced technology. The education development level (*EDL*) is expressed as the number of university students per 10,000 people [21]. (4) Population agglomeration can provide sufficient labor for the development of the tourism industry but also can increase social burdens and have an impact on the environmental system. Population density (*PD*) is expressed as the ratio of the real population to the urban land area at the end of the year [52]. (5) Infrastructure is an important objective condition for the smooth progress of tourism activities; infrastructure affects the optimization of factor layouts and has a significant impact on the green and intensive development of tourism. The infrastructure level (*IL*) is expressed as the ratio of road mileage to land area [49].

Models

Super-SBM Model with Undesirable Output

The SBM model is an improved version of the traditional DEA model. The model solves radial and angular deviations and allows for a more accurate evaluation of the relationship between input and output; however, further distinguishing the differences in efficient decision units (DMUs) with an efficiency of 1 when measuring efficiency is difficult. The Super-SBM model with undesirable outputs avoids the phenomenon of multiple DMUs being completely effective and unable to be effectively evaluated and ranked, and the measurement results are more in line with reality. In addition, a series of unexpected outputs may exist during tourism activities. Therefore, this paper adopts the Super-SBM model with undesirable outputs to measure China's tourism ecological efficiency. The formula is as follows:

$$\begin{cases} \min\rho = \left(1 - \frac{1}{m}\sum_{i=1}^{m}\frac{s_i^-}{x_{tk}}\right) / \left[1 + \frac{1}{q_1+q_2}\left(\sum_{r=1}^{q_2}\frac{s_t^{b-}}{y_{tk}} + \sum_{r=1}^{q_1}\frac{s_r^+}{y_{rk}}\right)\right] \\ \text{s.t.} \\ x_k = X\lambda + s^-, y_k = Y\lambda - s^+, b + k = b\lambda + s^{b-} \\ \lambda \geq 0, s_i^- \geq 0, s_r^+ \geq 0, s_t^{b-} \geq 0 \end{cases} \tag{9}$$

where ρ is efficiency; m, q_1, and q_2 are the number of indicators for inputs, desired outputs and undesired outputs; x_k, y_k, and b_k are input, desired output and undesired output variables; x_{ik}, y_{ik}, and b_{ik} are elements of input and output vectors; X, Y, and B are input-output matrices; and s_i^-, s_r^+, and s_t^{b-} are slack variables of input, desired output and undesired output. λ are column vectors.

Benchmark Regression Model

To examine the direct impact of the digital economy on tourism eco-efficiency and to verify hypothesis 1 (H1), this paper constructs a panel fixed effects model:

$$TEE_{it} = \alpha_0 + \alpha_1 Dige_{it} + \alpha_c Z_{it} + \varepsilon_{it} \tag{10}$$

where *TEE* is the explanatory variable, namely, tourism ecological efficiency. *Dige* is the urban digital economy development index. Z is a series of control variables. ε represents a random perturbation term. A significantly positive regression coefficient α_1 indicates that the development of the digital economy has a direct positive and significant impact on improvements in tourism eco-efficiency.

Mediating Effects Model

To explore the mediating effects that exist in the mechanism of the digital economy's impact on urban economic resilience and to test hypothesis 2 (H2),

Author Copy • Author Copy • Author Copy • Author Copy • Author Copy • Author Copy • Author Copy • Author Copy • Author Copy • Author Copy

this paper chooses digital technology-related patent innovation vitality and industrial structure advancement as mediating factors. The specific model is constructed as follows:

$$\mathrm{Dtiv_{it}} = \beta_0 + \beta_1 \mathrm{Dige_{it}} + \beta_c \mathrm{Z_{it}} + \varepsilon_{it} \quad (11)$$

$$\mathrm{TEE_{it}} = \gamma_0 + \gamma_1 \mathrm{Dige_{it}} + \gamma_2 \mathrm{Dtiv_{it}} + \gamma_c \mathrm{Z_{it}} + \varepsilon_{it} \quad (12)$$

$$\mathrm{Ais_{it}} = \omega_0 + \omega_1 \mathrm{Dige_{it}} + \omega_c \mathrm{Z_{it}} + \varepsilon_{it} \quad (13)$$

$$\mathrm{TEE_{it}} = \eta_0 + \eta_1 \mathrm{Dige_{it}} + \eta_2 \mathrm{Ais_{it}} + \eta_c \mathrm{Z_{it}} + \varepsilon_{it} \quad (14)$$

where digital technology-related patent innovation vitality (*Dtiv*) and industrial structure advancement (*Ais*) are mediating variables, and the meanings of the other variables are equivalent to those in Equation (11). If the regression coefficients $\beta 1$, $\gamma 1$, $\gamma 2$, $\omega 1$, $\eta 1$ and $\eta 2$ are significantly positive, then the innovation vitality of digital technology-related patents and industrial structure advancement are assumed to play a mediating role in the improvements in tourism eco-efficiency through the development of the digital economy. This role is significant.

Spatial Econometric Model

A spatial econometric model is selected for the empirical analysis to examine the spatial spillover effects of the digital economy on tourism eco-efficiency. However, before constructing the spatial econometric model, this paper uses Moran's I indices to explore the spatial agglomeration indices of the digital economy and tourism eco-efficiency. The expressions are given in Equation (15).

$$I = \frac{n\sum_{i=1}^{n}\sum_{j=1}^{n} w_{ij}(Y_i - \bar{Y})(Y_j - \bar{Y})}{S^2 \sum_{i=1}^{n}\sum_{j=1}^{n} w_{ij}} (i \neq j) \quad (15)$$

where i and j denote different cities; $S^2 = {}^1/_n \sum_{i=1}^{n}(Y_i - \bar{Y})^2$ and $\bar{Y} = {}^1/_n \sum_{n=1}^{n} Y_i$; Y_i and Y_j represent the observations of the spatial cell; w_{ij} is the spatial weight matrix; and I takes values between −1 and 1. The spatial correlation is negative when I is less than -1, spatially uncorrelated when it is equal to 0, and spatially positive when it is greater than 0. The larger the absolute value of I is, the stronger is the spatial correlation.

After the spatial agglomeration index is measured, spatial econometric models are subsequently constructed. The spatial econometric models used include SRM, SEM, and SDM. The spatial Durbin model, as a comprehensive form of the SEM and SRM without endogeneity problems [53], compensates for the shortcomings in traditional econometrics that cannot introduce spatial factors. The model expression is shown in Equation (16):

$$\mathrm{TEE_{it}} = a_0 + \rho \mathrm{WTEE_{it}} + \beta_1 \mathrm{WDige_{it}} + \theta_1 \mathrm{Dige_{it}} + \beta_2 \mathrm{WControl_{it}} + \theta_2 \mathrm{WControl_{it}} + \mu_i + \delta_t + \varepsilon_{it} \quad (16)$$

where W is the spatial weight matrix, and the geographical weight matrix (W) is selected in this paper. The geographical distance between cities is calculated based on the geographical coordinates between cities. ρ is the spatial regression coefficient of the explanatory variable, and β_1 and β_2 are the spatial regression estimation coefficients of the explanatory and control variables, respectively. θ_1 and θ_2 are the spatial regression estimated coefficients of the explanatory and control variables, respectively. μ_i and δ_t are city and time fixed effects, ε_{it} is the random error term, and X denotes the control variable.

Data Acquisition and Illustration

The data sources include the China City Statistical Yearbook (2012~2020), the China Tourism Statistical Yearbook (2012~2018), the China Tourism and Culture Statistical Yearbook (2019), the China Cultural Relics and Tourism Statistical Yearbook (2020), and the CNRDS (www.cnrds.com). In addition, to avoid multicollinearity and pseudoregression disturbances, the panel data were subject to the variance inflation factor (VIF) test and unit root test. The results show that the VIFs of the panel data are less than 5, and all of them pass the LLC test and Fisher-ADF test at the 1% significance level. Thus, the data do not have a multicollinearity problem and are smooth.

Results

Calculation Results of Tourism Eco-Efficiency

Regional Feature Analysis

This paper uses the Super-SBM model with undesirable outputs to calculate China's tourism eco-efficiency index from 2011 to 2019. As shown in Fig. 2, the average value of China's tourism eco-efficiency decreased from 0.6337 to 0.5786 from 2011 to 2019, reflecting a cumulative growth rate of 18.76% and an average annual growth rate of 2.23%. Specifically, overall tourism eco-efficiency shows an upward trend of varying magnitude. An inflection point existed in 2017 after a continuous increase from 2011 to 2016. After that, it continued to increase, indicating that China's tourism eco-efficiency has better development prospects. Based on the Division Method of East, Central, West, and Northeast China issued by the National Bureau of Statistics of China, this paper further divides the study area into four regions: East, Central, West, and Northeast. The central region has the largest change in TEE (cumulative growth rate

Author Copy • Author Copy • Author Copy • Author Copy • Author Copy • Author Copy • Author Copy • Author Copy • Author Copy

of 38.53%), followed by the northeast region (cumulative growth rate of 24.37%). The east region has the smallest change (cumulative growth rate of 8.68%). The efficiency distribution pattern of "East>Northeast>Central>West" was gradually established after 2011.

Analysis of Spatiotemporal Patterns

The data from 2011, 2015, and 2019 are visualized and analyzed using the natural breakpoint method to reveal the spatial and temporal evolution characteristics of tourism eco-efficiency in the different cities (Fig. 3). Regarding temporal evolution, tourism eco-efficiency increased in most cities from 2011 to 2019, with a breakthrough in the highest efficiency. Regarding spatial patterns, 182 cities had tourism eco-efficiency levels lower than the mean in 2011, accounting for 66.18% of the study area. The number of cities below the efficiency mean decreased in 2015 and 2019, both accounting for 64.00% of the study area. Regarding the evolution of regional patterns, high-efficiency zones are mainly concentrated in coastal cities in the eastern and northeastern regions and spread to inland regions of China at the end of the study. The inefficiency regions are clustered in central China, western China, and northern cities in northeastern China at the beginning of the study, and are dispersed at the end of the study.

Direct Effects

The fixed effects model is chosen after the Hausman test was passed, and a benchmark regression is run with control variables (Table 2). The regression results show that the regression coefficients of the digital economy pass the 1% significance level before and after adding control variables, which indicates that the development of the digital economy has a significant positive impact on tourism eco-efficiency. Thus, hypothesis 1 is supported. Specifically, for each control variable, the effects of economic density, urbanization level,

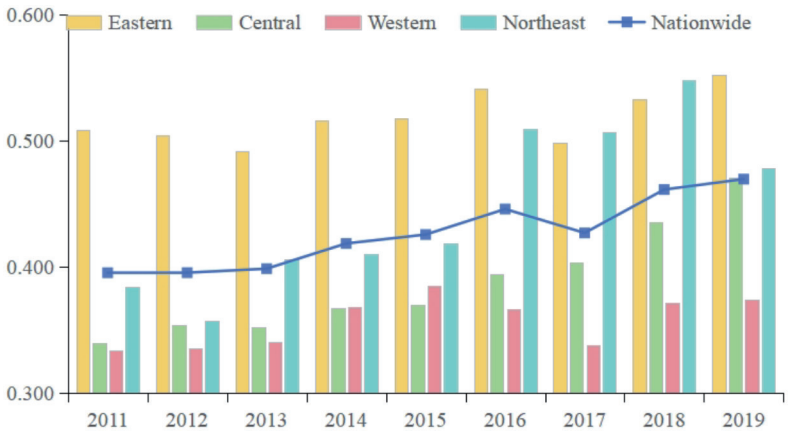

Fig. 2. Annual average tourism eco-efficiency in different regions from 2011 to 2019.

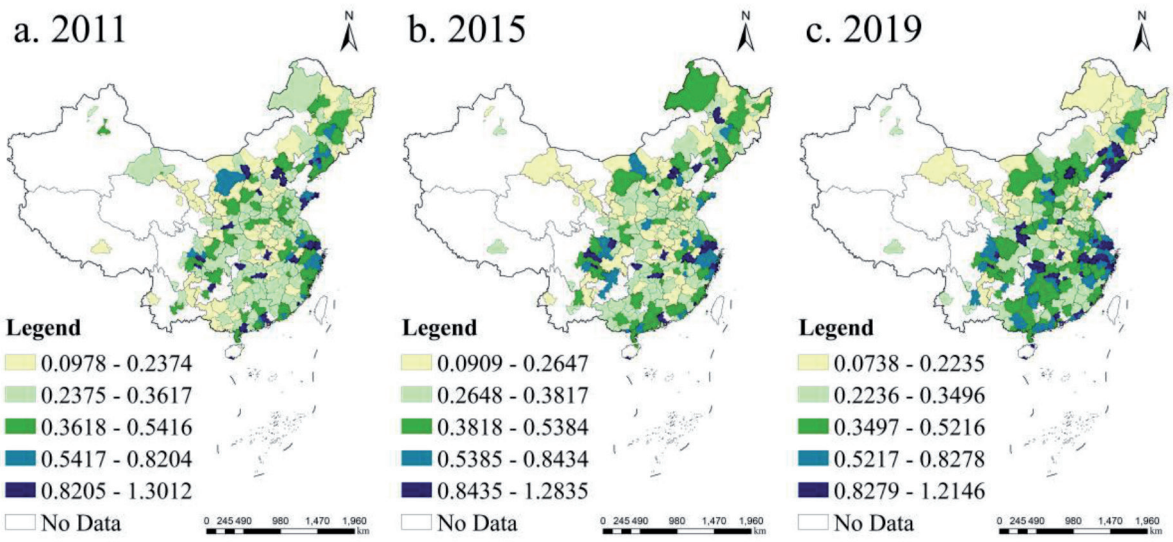

Fig. 3. The spatiotemporal characteristics of tourism eco-efficiency.

Author Copy • Author Copy • Author Copy • Author Copy • Author Copy • Author Copy • Author Copy • Author Copy • Author Copy • Author Copy

Table 2. Direct effects.

Variables	(1)	(2)	(3)	(4)	(5)	(6)
Dige	0.4483***	0.4483***	0.3763***	0.3742***	0.3762***	0.4152***
ED		-0.0000**	-0.0000**	-0.0000**	-0.0000**	-0.0000***
UL			0.1983***	0.1981***	0.2029***	0.2070***
EDL				-0.0000	-0.0000	-0.0000
PD					0.0002***	0.0002*
IL						-0.0000**
Constant	0.3627 ***	0.3627 ***	0.2927 ***	0.2985 ***	0.2108 ***	0.2376 ***
City FE	YES	YES	YES	YES	YES	YES
Year FE	YES	YES	YES	YES	YES	YES
Observations	2475	2475	2475	2475	2475	2475
R−squared	0.0441	0.0441	0.0656	0.0565	0.0897	0.1103
F−statistic	32.35	32.35	32.27	31.38	30.72	29.91

Note: *, **, and *** represent significance at the 10%, 5%, and 1% levels, respectively.

Table 3. Robustness check.

Variables	Explanatory Variables with One Period Lag	Replace Explained Variable	Add Control Variable
L.Dige	0.4302 ***		
MI		0.9367 ***	0.5644 ***
GML			-0.0000***
Constant	0.2414 ***	1.1364 ***	0.3405 ***
Control	YES	YES	YES
City FE	YES	YES	YES
Year FE	YES	YES	YES
Observations	2200	2475	2475
R−squared	0.1131	0.0087	0.0365
F−statistic	27.00	1.35	26.72

Note: *, **, and *** represent significance at the 10%, 5%, and 1% levels, respectively.

population density, and infrastructure on tourism eco-efficiency are tested at the 1% and 10% significance levels. Among them, the urbanization level and population density play a positive role in tourism eco-efficiency. This is because urbanization involves the transformation of social and economic structures, such as population and industrial structures, which can encourage the concentration of resources such as capital, information, and talent; accelerate improvements in the economic efficiency of the tourism industry; and help in the construction of a green ecological environment. Economic density and infrastructure level have negative impacts on tourism eco-efficiency. This is because regions with higher economic development and more extensive infrastructure development are more severely challenged in terms of their environmental carrying capacity, which hinders the development of tourism eco-efficiency. In addition, the effect of education level on tourism eco-efficiency is not significant, indicating that the dependence of tourism eco-efficiency improvements on the education level is not significant.

Robustness Check

Based on the results of the benchmark regression, this paper conducts robustness tests using core explanatory variables lagged by one period, substitute explanatory variables, and add control variables (Table 3). The original tourism eco-efficiency (*TEE*) is replaced by the tourism eco-efficiency (*MI*) measured using the

Author Copy • Author Copy • Author Copy • Author Copy • Author Copy • Author Copy • Author Copy • Author Copy • Author Copy • Author Copy

Super-SBM-GML model with undesirable outputs for the robustness test. Since there may be some lags in digital economy benefits, the core explanatory variables are included in the benchmark regression with a one-year lag for robustness testing. For the robustness test, government management regulation (*GMI*) is added as a control variable to the benchmark regression. After testing, the model results are consistent with the original results, indicating that the original benchmark model is robust.

Heterogeneity Analysis

Considering the possible spatial heterogeneity of the impact of the digital economy on tourism eco-efficiency, this paper divides cities according to the region in which they are located and whether they belong to city clusters or not. The criteria for the division of regions and city clusters come from the Division Method of East, Central, West, and Northeast China and the results of relevant studies [54]. The region is first divided into eastern, central, western, and northeastern regions to test the regional heterogeneity of the impact of the digital economy on tourism eco-efficiency. For the sake of space, Table 4 shows only the impact coefficients of the core explanatory variable – the digital economy. As shown in Table 4, only the central and northeastern cities show significant impact effects, with the highest coefficient occurring in the northeast, and the eastern and western cities do not pass the significance test. Eastern cities have a strong economic base, a higher degree of rationalization and advanced industrial structure, and an established paradigm for promoting tourism eco-efficiency [21]. In contrast, the ability to improve tourism eco-efficiency by relying on the digital economy is not prominent. The digital infrastructure construction and digital technology of the western cities are weaker, making it difficult to fully utilize the positive effects of the digital economy on tourism eco-efficiency. Most of the northeastern cities are resource-based cities, and problems such as resource consumption, serious pollution, and the irrational phenomenon of industrial structure exist. During the current vigorous development of industrial and ice tourism, the digital economy can play an important role in enhancing the economic growth of tourism and optimizing ecological benefits. Central cities can enjoy the spillover dividends of digital technology and talent from eastern cities due to their proximity to eastern cities; at the same time, they have strong tourism resource endowments and tourism industry agglomeration advantages. The development of the digital economy can meet the needs of the local tourism industry in terms of tourism application scenarios and has extensive development potential for improving tourism eco-efficiency.

According to Zhang [54], this paper classifies cities into city clusters and noncity cluster samples according to whether they belong to 13 city clusters, such as the Yangtze River Delta and Beijing-Tianjin-Tangshan. A city cluster is an agglomeration of cities that transcends the "specialization and diversification economy" within cities and reduces the barriers between cities to form the "agglomeration effect" of "1+1>2". Regarding the spatial heterogeneity of city clusters, the digital economy in both city and noncity clusters has a significant impact on tourism eco-efficiency; however, the impact effect is stronger in noncity clusters. This finding suggests that the development of the digital economy in both city and noncity clusters can promote regional tourism eco-efficiency and that city clusters do not reflect the "city cluster effect" that should have been compared to noncity clusters.

Mediating Effects

According to the previous theoretical analysis, technological effects and industrial restructuring are the key factors that help the efficiency of tourism ecology improve in the digital economy. The technology effect is characterized by the number of digital economy-related patent applications per 10,000 people, and the industrial structure adjustment is characterized by the industrial structure advanced index, with reference to Fu [55]. This paper adopts the mediating effects model to analyze

Table 4. Heterogeneity analysis.

Variables	Eastern Cities	Central Cities	Western Cities	Northeastern Cities	City Clusters	Non-City Clusters
Dige	0.0767	0.8958 ***	0.1342	0.9904 ***	0.3141 ***	0.4648 ***
Control	YES	YES	YES	YES	YES	YES
City FE	YES	YES	YES	YES	YES	YES
Year FE	YES	YES	YES	YES	YES	YES
Observations	765	720	693	297	1143	1332
R−squared	0.0371	0.0370	0.0596	0.2925	0.1820	0.0171
F−statistic	35.02	37.42	18.86	10.41	31.20	22.84

Note: *, **, and *** represent significance at the 10%, 5%, and 1% levels, respectively.

Author Copy • Author Copy • Author Copy • Author Copy • Author Copy • Author Copy • Author Copy • Author Copy • Author Copy • Author Copy

the relevant mechanisms between the digital economy and tourism eco-efficiency.

As shown in the regression results in Table 5, the regression coefficients of the technology effect and industrial structure adjustments are significantly positive regardless of whether or not the control variables are added. This indicates that the technology effect and industrial structure adjustments play mediating roles in the effect of the digital economy on tourism eco-efficiency. Given the technology effect, every 1% increase in the digital economy increases tourism eco-efficiency by 0.4668%. This finding shows that the development of a digital economy can realize the effective matching between the supply and demand sides of the tourism industry, improve the utilization efficiency of resources through technological effects, enhance the environmental monitoring capacity of tourism destinations with the help of new types of technologies, and simultaneously strengthen regional environmental governance capacities. Given industrial structure adjustments, every 1% increase in the digital economy increases tourism eco-efficiency by 0.2506%. This finding indicates that the regional industrial structure is constantly transformed toward cleanliness and efficiency under the influence of the "crowding out effect", thus realizing the organic unity of economic growth and environmental improvements in tourism destinations. Thus, hypothesis 2 is supported.

Spatial Spillover Effects

The spatial correlation between the digital economy and tourism eco-efficiency is first tested. In this research, the global Moran's I under the geographical weight matrix (W) is used to explore the spatial clustering characteristics of the two variables (Table 6). As shown in Table 6, under the geographical weight matrix, the Moran's I values of both *Dige* and *TEE* are positive and pass the significance test at the 1% level, which indicates that the digital economy and tourism eco-efficiency have significant spatial clustering characteristics and can be studied from a spatial perspective.

The above studies prove a significant spatial correlation between the digital economy and tourism eco-efficiency; thus, further spatiotemporal effects of the impact of the digital economy on tourism eco-efficiency are needed. First, this paper performs LM, LR, and Wald tests to identify spatial econometric models (Table 7). Both the LM spatial lag and LM spatial error tests reveal substantial significance under the inverse distance weight matrix; therefore, both SAR and SEM models are suitable for this study. Second, this paper further determines whether the SDM degenerates into the SAR and SEM models by applying the LR and Wald tests. The combined test shows that the SDM model is superior to the SAR and SEM models. On the basis of the SDM, this paper selects the fixed effects model given the Hausman test results. However, since the individual fixed and double fixed comparisons do not pass the LR test, the time-fixed effects are selected after a comprehensive comparison.

The spatial Durbin model can be used to determine whether there are spatial spillovers from the digital economy on tourism eco-efficiency. As shown in Table 8, the spatial autoregressive coefficient of tourism eco-efficiency under the geographical weight matrix

Table 5. Mediating effects analysis.

Variables	Technological Effect		Industry Structure Adjustment	
	(1)	(2)	(1)	(2)
Dige	0.4668 ***	0.5330 ***	0.1237 *	0.2506 ***
Control	NO	YES	NO	YES
City FE	YES	YES	YES	YES
Year FE	YES	YES	YES	YES
Observations	2475	2475	2475	2475
R-squared	0.0033	0.0381	0.2397	0.1666
F-statistic	31.65	26.74	27.12	23.81

Note: *, **, and *** represent significance at the 10%, 5%, and 1% levels, respectively.

Table 6. Global Moran's I of the digital economy and tourism eco-efficiency.

Year	2011	2012	2013	2014	2015	2016	2017	2018	2019
Dige	0.085 ***	0.098 ***	0.087 ***	0.084 ***	0.085 ***	0.080 ***	0.099 ***	0.097 ***	0.073 ***
TEE	0.014 ***	0.024 ***	0.020 ***	0.026 ***	0.024 ***	0.028 ***	0.027 ***	0.026 ***	0.052 ***

Note: *, **, and *** represent significance at the 10%, 5%, and 1% levels, respectively.

Author Copy • Author Copy • Author Copy • Author Copy • Author Copy • Author Copy • Author Copy • Author Copy • Author Copy • Author Copy

Table 7. Spatial econometric model validation.

Inspection Method	Characteristic Value
LM Spatial Lag	39.909 ***
Robust LM Spatial Lag	36.428 ***
LM Spatial Error	186.194 ***
Robust LM Spatial Error	146.402 ***
Hausman test	14.75 **
Individual Fixed and Double Fixed (LR test)	13.94
Time Fixed and Double Fixed (LR test)	3091.93 ***
Wald-Lag test	47.07 ***
Wald-Error test	23.37 ***
LR-Lag test	46.35 ***
LR-Error test	21.02 ***

Note: *, **, and *** represent significance at the 10%, 5%, and 1% levels, respectively.

Table 8. Spatial econometric model results.

Variables	*W*
Dige	0.0183 *
W * *Dige*	1.3407 ***
Direct Effect	0.0090 *
Indirect Effect	6.9618 ***
Total Effect	6.9708 *
Rho	0.7912 ***
R^2	0.0049
Log -likelihood	-1603.2946
Control	YES
N	2475
City FE	NO
Year FE	YES

Note: *, **, and *** represent significance at the 10%, 5%, and 1% levels, respectively.

is 0.7912, which passes the significance test at the 1% level. A 1% increase in local tourism eco-efficiency leads to a 0.7912% increase in neighboring tourism eco-efficiency, further demonstrating the necessity of exploring the effect of the digital economy on tourism eco-efficiency from a spatial spillover perspective. In addition, both Dige and W*Dige are positive and pass the significance test, tentatively indicating that the digital economy can promote the existence of positive spatial spillovers in tourism eco-efficiency.

The coefficients in the estimated results of the spatial Durbin model do not indicate the effect of spillovers and cannot specifically explain the spillover effects of the digital economy on tourism eco-efficiency; therefore, they need to be further decomposed into direct, indirect, and total effects. The decomposition results in Table 8 show that both the direct and indirect effects of the digital economy under the inverse distance matrix are positive and largely pass the significance test. Every 1% increase in the digital economy can promote the tourism eco-efficiency of neighboring places by 6.9618% and is significant at the 1% level, indicating that the digital economy can improve the tourism eco-efficiency of neighboring places through spatial spillover benefits. Neglecting spatial factors underestimates the effect of the digital economy. The above conclusions are verified, and Hypothesis 3 is supported.

Conclusions and Discussion

Conclusions

In the context of the digital economy, the development of the tourism industry has attracted new opportunities, and new paths have been taken to improve tourism eco-efficiency. However, existing research has not explored whether and how the digital economy can promote tourism eco-efficiency. Therefore, this paper first analyzes the mechanism through which the digital economy affects tourism eco-efficiency and proposes corresponding research hypotheses on this basis. This paper uses 275 prefecture-level and above cities in China as the research sample and a benchmark regression model, a mediation effects model, and a spatial Durbin model to explore the effect of the digital economy on tourism eco-efficiency. The research findings are as follows.

First, the digital economy has a significant positive effect on tourism eco-efficiency. When this paper does not include control variables, every 1% increase in the digital economy promotes tourism eco-efficiency by 0.4483%. With the inclusion of a series of control variables, tourism eco-efficiency increases by 0.4152% for every 1% increase in the digital economy. However, spatial heterogeneity exists in the effect of the digital economy on tourism eco-efficiency. The impact of the digital economy is more pronounced in the central and northeastern regions of China than in the eastern and western regions. In addition, the impact of the digital economy on tourism eco-efficiency within city clusters does not have a good “clustering effect”.

Second, the digital economy positively affects tourism eco-efficiency by exerting technological effects and industrial structural adjustments. Without considering the control variables and adding the two mediating variables of the number of digital economy-related patent applications per 10,000 people

Author Copy • Author Copy • Author Copy • Author Copy • Author Copy • Author Copy • Author Copy • Author Copy • Author Copy • Author Copy

and the industrial structure advanced index, the coefficients of the effect of the digital economy on tourism eco-efficiency are 0.4668 and 0.1237, respectively, and significantly positive. After adding the control variables, the coefficients of the effect of the digital economy on tourism eco-efficiency under the mediating effects are 0.5330 and 0.2506, respectively, and significantly positive.

Third, the digital economy has significant positive spatial spillover effects on tourism eco-efficiency. First, there is a spatial spillover phenomenon of tourism eco-efficiency. Every 1% increase in local tourism eco-efficiency can increase neighboring tourism eco-efficiency by 0.7912%. Second, the digital economy has equally significant and positive effects on local and neighboring tourism ecology. Given the inverse distance matrix, every 1% increase in the digital economy can increase local tourism and neighboring tourism eco-efficiency by 0.0090% and 6.6918%, respectively.

Discussion

Theoretical Implications

Studying tourism eco-efficiency from the perspective of the digital economy context is important. In this paper, we provide several theoretical innovations based on the shortcomings of the established research. First, this paper constructs a mechanistic framework for how the digital economy affects tourism eco-efficiency and explores the mechanism through which the digital economy affects tourism eco-efficiency in local and neighboring areas from a multidisciplinary perspective. On this basis, this paper constructs an econometric model to empirically test and analyze the effect of the digital economy on tourism eco-efficiency in different cities, which provides a paradigm for future related studies with other cities as samples. Second, this paper applies the mediating effects model and confirms that the role of technological effects and industrial structure adjustments on eco-efficiency [9] is also applicable in the field of tourism and that the mechanism of action may be correlated with eco-efficiency in categories such as cities and regions. This theoretical evidence provides a scientific reference for policy development in regions or cities. Finally, using the spatial Durbin model, this paper also confirms that the digital economy has positive spatial spillover effects on neighborhood tourism eco-efficiency. Compared with established studies [20], this paper has integrated geospatial perspectives in tourism eco-efficiency-related studies, which not only enhances the objectivity of the conclusions but also strengthens interdisciplinary communication.

Practical Implications

Based on the above findings, this paper proposes several feasible recommendations from the regional and stakeholder perspectives as a reference.

This paper combines the tourism eco-efficiency measure and the results of the digital economy impact effect test and shows that the tourism eco-efficiency of the central and northeastern cities has a significant upward trend during the study period – during which the digital economy plays an important role. In the future, central and northeastern cities should fully exploit spatial spillover effects, assume the efficacy of the digital economy between the East and the West, strengthen cooperation and ties with neighboring cities, and explore collaborative mechanisms for building and sharing to improve the overall sustainable development of the tourism industry. Tourism eco-efficiency in eastern cities is high among the four regions, but the digital economy is not. Because they are in the region that is at the forefront of China's economic and urbanization development, eastern cities can strengthen the exploration of the use of the digital economy for eco-efficiency building in the field of tourism and can act as a benchmark for the entire country, especially the regions with dense tourism resources. Western cities are among the densely populated areas of China's tourism resources. At the same time, the ecological environment in these important areas are in need of urgent improvement. Therefore, on the one hand, western cities should fully draw on external spillover dividends from eastern and central cities to enhance their own digital strength. On the other hand, internally, the internal cross-regional cooperation mechanism should be improved and focus on fully considering the diffusion effect of the growth pole of the digital economy in western cities to avoid the negative impact on neighboring provinces and regions and promote sustainable and high-quality development of intra and interregional development.

Over the years, sustainable tourism development has attracted substantial attention from all sectors of society. How tourism can maximize economic benefits at the lowest environmental cost and improve eco-efficiency requires the joint efforts of different stakeholders. Importantly, the government must act as a leader in tourism eco-efficiency. The first task of the tourism sector is to promote the integration of IoT, 5G, and AI-capable digital technologies into tourism to broaden tourism application scenarios. Second, strengthening tourism digitalization and environmental regulation is necessary to match and provide better policy support for the digital economy and to apply tourism eco-efficiency construction. In addition to relying on the Internet platform to broaden their distribution channels to obtain greater economic benefits, enterprises also need to give full play to the relative optimization brought about by digital transformation and accurately control supply and demand to avoid falling into the trap of disorderly development that results in a waste of resources and environmental damage. In addition, the construction of a digital tourism platform is important for tourism-related traffic detection, resource allocation, and early warning deployment. The media and tourists are also

Author Copy • Author Copy • Author Copy • Author Copy • Author Copy • Author Copy • Author Copy • Author Copy • Author Copy • Author Copy

important stakeholders in the development of tourism eco-efficiency. The former builds a communication bridge between the government and the public with the help of digital media and assists the government in spreading the public demand for civilized tourism, whereas the latter is one of the basic mainstays in practicing sustainable tourism development.

Limitations and Future Research

Although this paper confirms that the digital economy has a positive impact on tourism eco-efficiency and provides theoretical contributions and practical guidance for the development of China's tourism industry, there are still areas that can be further improved. First, the impact of the digital economy on tourism eco-efficiency may have a marginal effect, which can be explored in the future using a threshold effects model. Second, there may be limitations in using transformed environmental pollution data as undesired outputs due to data access limitations. Third, this paper uses 275 prefecture-level and above cities in China as the research sample, whereas the urban economic links and factor flows between microregions are closer. Therefore, in the future, this paper can analyze the targeted problems around specific regions, such as the Yangtze River Economic Belt, the Yellow River Basin, and other areas.

Acknowledgments

This research was funded by the National Office for Philosophy and Social Sciences Project (No. 21FGLB070).

Conflict of Interest

The authors declare no conflict of interest.

References

1. KICHERER A., SCHALTEGGER S., TSCHOCHOHEI H., POZO B.F. Eco-efficiency: Combining Life Cycle Assessment and Life Cycle Costs via Normalization. The International Journal of Life Cycle Assessment, **7**, 537, **2007**.
2. WU Y.Q., ZHANG X. Evaluation on the Green Development of Provincial Economy in China-based on the Perspective of Green Total Factor Productivity. Journal of Hebei University of Economics and Business, **43**, 67, **2022**.
3. ZHANG M., ZHANG G., LIU H. Analysis of the impact of tourism development on the urban-rural income gap: Evidence from 248 prefecture-level cities in China. Asia Pacific Journal of Tourism Research, **26**, 614, **2021**.
4. WANG M.K,, LIU Y.P. Threshold effect of tourism development on urban-rural income gap-based on the provincial panel data in China. Inquiry into Economic Issues, **12**, 30, **2018**.
5. JAYASINGHE M., SELVANATHAN E.A. Energy consumption, tourism, economic growth and CO_2 emissions nexus in India. Journal of the Asia Pacific Economy, **26**, 361, **2021**.
6. KONG L.Z., LI J.Y. Study on the Influence of Digital Economy Development on Regional Eco-efficiency. Statistics & Decision, **39**, 23, **2023**.
7. LIU Z., YANG Y., SUI X.Y. Internet development, market vitality stimulation and tourism economic growth-Analysis based on the perspective of spatial spillover. Tourism Science, **36**, 17, **2022**.
8. SU J.Q., SU K., WANG S.B. Does the Digital Economy Promote Industrial Structural Upgrading? A Test of Mediating Effects Based on Heterogeneous Technological Innovation. Sustainability, **13**, 10105, **2021**.
9. CHEN S., HAN L., XU M. An Analysis of the Impact Mechanism of Digital Economy on Urban Ecological Environment and Its Heterogeneity. Journal of Soochow University (Philosophy & Social Science Edition), **44**, 138, **2023**.
10. CHEN L.L., XU J.H., LI Y.J. Theoretical mechanism and Path Exploration of digital technology enabling high-quality development of Tourism. Reform, **2**, 101, **2022**.
11. SIMON A., DUAN P.F., CHRISTIAN N. International trade and economic growth in Africa: The role of the digital economy. Cogent Economics & Finance, **9**, 1911767, **2021**.
12. XU X.C., REN X., CHANG Z.H. Big Data and Green Development. China Industrial Economics, **37**, 5, **2019**.
13. CAIADO R.G.G., DE FREITAS DIAS R., MATTOS L.V., QUELHAS O.L.G., LEAL FILHO W. Towards sustainable development through the perspective of eco-efficiency-a systematic literature review. Journal of Cleaner Production, **165**, 890, **2017**.
14. LIU J., MA Y. The Perspective of Tourism Sustainable Development: A Review of Eco-efficiency of Tourism. Tourism Tribune, **32**, 47, **2017**.
15. GÖSSLING S., PEETERS P., CERON J.P., DUBOIS G., PATTERSON T., RICHARDSON, R.B. The Eco-efficiency of Tourism. Ecological Economics, **54**, 417, **2005**.
16. LYU Y.P., TAI J., CHE Y., WU B.S., XIA S.X. Regional sustainability based on comprehensive measurement of background ecological footprint and tourism ecological footprint: A case study of Southeast Qian. Journal of Mountain Science, **25**, 698, **2007**.
17. SABINE P., ANA S., MATTHIAS S. The greenhouse gas intensity of the tourism sector: The case of Switzerland. Environmental Science & Policy, **13**, 131, **2010**.
18. BRUIJN K.D., DIRVEN R., EJGELAAR E., PEETERSET P., NELEMANSAL R. Travelling large in 2011: The carbon footprint of Dutch holiday makers in 2011 and the development since 2002, NHTV Breda University of Applied Sciences: Breda, Netherlands, **2013**.
19. GUO T.T., WANG J.D., LI C. Spatial-Temporal Evolution and Influencing Mechanism of Tourism Ecological Efficiency in China. Sustainability, **14**, 16880, **2022**.
20. ZHANG Y., LI Y. Regional Differences in Tourism Eco-Efficiency in the Beijing-Tianjin-Hebei Region: Based on Data from 13 Cities. Sustainability, **15**, 2907, **2023**.
21. WU X.Y., LIANG X.C. Tourism development level and tourism eco-efficiency: Exploring the role of environmental regulations in sustainable development. Sustainable Development, **31**, 2863, **2023**.

Author Copy • Author Copy • Author Copy • Author Copy • Author Copy • Author Copy • Author Copy • Author Copy • Author Copy • Author Copy

22. ZHANG F., YANG X., WU J., MA D., XIAO Y., GONG G., ZHANG J. How New Urbanization Affects Tourism Eco-Efficiency in China: An Analysis Considering the Undesired Outputs. Sustainability, **14**, 10820, **2022**.
23. CASTILHO D., FUINHAS J.A., MARQUES A.C. The impacts of the tourism sector on the eco-efficiency of the Latin American and Caribbean countries. Socio-Economic Planning Sciences, **78**, 101089, **2021**.
24. TAPSCOTT D., MCQUEEN R. The digital economy: Promise and peril in the age of networked intelligence. Bambook, **10**, 69, **1996**.
25. NEGROPONTE N. Being Digital, Random House: New York, America, **1996**.
26. SUN X.X., CHEN Z.W., SHI T.T., YANG G.Q., YANG X.Y. Influence of digital economy on industrial wastewater discharge: Evidence from 281 Chinese prefecture-level cities. Journal of Water & Climate Change, **13**, 593, **2022**.
27. XU X.C., ZHANG M.H. Research on the Scale Measurement of China's Digital Economy-Based on the Perspective of International Comparison. China Industrial Economics, **38**, 23, **2020**.
28. JIAO S.T., SUN Q.B. Digital Economic Development and Its Impact on Economic Growth in China: Research Based on the Perspective of Sustainability. Sustainability, **13**, 10245, **2021**.
29. ASONGU S.A. ICT, openness and CO2 emissions in Africa. Environmental Science and Pollution Research, **25**, 9351, **2018**.
30. ULUCAK R., KHAN S. Does Information and Communication Technology Affect CO2 Mitigation Under the Pathway of Sustainable Development During the Mode of Globalization. Sustainable Development, **28**, 857, **2020**.
31. OLÁH J., KITUKUTHA N., HADDAD H., PAKURÁR M., MÁTÉ D., POPP J. Achieving Sustainable E-Commerce in Environmental, Social and Economic Dimensions by Taking Possible Trade-Offs. Sustainability, **11**, 89, **2018**.
32. ADEOLA O., EVANS O. Digital tourism: Mobile phones, internet and tourism in Africa. Tourism Recreation Research, **44**, 190, **2019**.
33. YANG L. Has the Internet promoted the dynamic optimization of the tourism industry? Journal of Business Management, **41**, 156, **2019**.
34. NUENEN T.V., SCARLES C. Advancements in technology and digital media in tourism. Tourist Studies, **21**, 119. **2021**.
35. KWOK A.O.J., KOH S.G.M. Is blockchain technology a watershed for tourism development? Current Issues in Tourism, **22**, 2447, **2018**.
36. LU L., MING L. How does the digital economy affect industrial eco-efficiency? Empirical evidence from China. Data Science in Finance and Economics, **2**, 371, **2022**.
37. YANG Y.W., LIANG Q.Y. Digital economy, environmental regulation and green eco-efficiency-Empirical evidence from 285 cities in China. Frontiers in Environmental Science, **11**, 1113293, **2023**.
38. CUI J.J., WANG W.J., CHEN Z.L., REN G.Q., GAO X.F. How digitalization and financial development impact eco-efficiency? Evidence from China. Environmental Science and Pollution Research, **30**, 3847, **2023**.
39. LIANG Q., XIAO S.P., LI M.X. Has the Development of Digital Economy Improved Urban Ecological Efficiency? – Based on the Perspective of Industrial Structure Upgrading. Inquiry into Economic Issues, **42**, 82, **2021**.
40. ZHAO T., ZHANG Z., LIANG S.K. Digital Economy, Entrepreneurship, and High-Quality Economic Development: Empirical Evidence from Urban China. Journal of Management World, **36**, 65, **2020**.
41. WANG R.Y., LIANG Q., LI G.Q. Virtual Agglomeration: A New Form of Spatial Organization with Deep Integration of New Generation Information Technology and Real Economy. Journal of Management World, **34**, 13, **2018**.
42. MURAD M.A. Scaling digital and non-digital business models in foreign markets: The case of financial advice industry in the United States. Journal of World Business, **58**, 101457, **2023**.
43. ZHANG W., ZHANG T., LI H., ZHANG H. Dynamic spillover capacity of R&D and digital investments in China's manufacturing industry under long-term technological progress based on the industry chain perspective. Technology in Society, **71**, 102129, **2022**.
44. ZHAO L. The Connotation and Dimensions of Digital Economy Enabling High-Quality Tourism Development. Tourism Tribune, **37**, 5, **2022**.
45. WANG F.Z., LIU X.L., ZHANG L., CHENG W.C. Does digitalization promote green technology innovation of resource-based enterprises? Studies in Science of Science, **40**, 332, **2022**.
46. LI Z.H., BAI T.T. Government environmental protection expenditure, green technology innovation and smog pollution. Science Research Management, **42**, 52, **2021**.
47. MA D., ZHU Q. Innovation in Emerging Economies: Research on the Digital Economy Driving High-Quality Green Development. Journal of Business Research, **145**, 801, **2022**.
48. GUO F., WANG J.Y., WANG F., KONG T., ZHANG X., CHENG Z.Y. Measuring China's Digital Financial Inclusion: Index Compilation and Spatial Characteristics. China Economic Quarterly, **19**, 1401, **2020**.
49. WANG Z.F., WANG Z.Y. The influence of environmental regulation on eco-efficiency of tourism industry in the middle reaches of Yangtze River urban agglomeration and its spatial differentiation. Journal of Ecology, **41**, 3917, **2021**.
50. LI Z., WANG D. Tourism economy in the Wuling Mountains region-Spatial and temporal variation of eco-efficiency and influencing factors. Economic Geography, **40**, 233, **2020**.
51. HUANG D.C., WANG Z.F. Evolution of Spatial Network Structure of Tourism Eco-efficiency and Its Effect of Urban Agglomeration in Middle Reaches of Yangtze River. Resources and Environment in the Yangtze Basin, **32**, 1, **2023**.
52. FENG J., YANG X.Z., WANG Q. Spatial-Temporal Pattern Evolution and Influencing Factors of Coupling Coordination between Tourism Efficiency and Ecological Well-Being Performance in the Mountainous Area of Southern Anhui Province, China. Mountain Research, **40**, 597, **2022**.
53. ZHAO Q.B., LI G.Q., GU X.H., LEI C.K. Inequality hikes, saving surges, and housing bubbles. International Review of Economics & Finance, **72**, 349, **2021**.
54. ZHANG F., NING Y.M., LOU X.Y. Competitiveness and regional inequality of China's mega-city regions. Geographical Research, **38**, 1664, **2019**.
55. FU L.H. An Empirical Research on Industry Structure and Economic Growth. Statistical Research, **27**, 79, **2010**.