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Spatial-temporal Evolution and Its Influencing Factors of Tourism Eco-efficiency in China

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ABSTRACT

Eco-efficiency is an invaluable indicator for the measurement of the relationship between production activities and environmental depletion. This study measures the tourism eco-efficiency of 30 provinces in China from 2005 to 2020 based on the super-efficiency SBM model, and explores its spatial-temporal evolution characteristics using the kernel density function, standard deviation ellipse, and center of the gravity model. Then, the influencing factors of the tourism eco-efficiency in China are analyzed by The Tobit regression model. The results show that the tourism eco-efficiency of China is generally fluctuating upwards, but has not yet reached the maximum production possibility frontier. The kernel density curve shows a unimodal-bimodal-unimodal pattern, while the inter-provincial differences have been decreasing and becoming more balanced. The center of gravity of tourism eco-efficiency is located at the junction of Henan province and Hubei province and generally moves to the south (slightly to the southwest). Meanwhile, it is revealed that the level of economic development and tourism eco-efficiency has a significant inverted U-shaped relationship. The level of economic openness, traffic conditions, and tourism eco-efficiency is positively correlated. The environmental regulations and industrial structure have a negative but limited impact on tourism eco-efficiency. Finally, recommendations and suggestions for policy formulation to promote quality and sustainable development of the tourism industry are put forward, such as increasing investment in ecological protection and governance in tourism development, improving capacity-building in allocating green and low-carbon technologies and resources, strengthening tourism infrastructure construction, and enhancing environmental governance systems and mechanisms.

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1. Introduction

After more than 40 years of unremitting efforts, China's tourism development has achieved world-renowned achievements. However, the increasing pressure on the tourism environment from increasingly frequent tourism activities has caused various problems associated with tourism resources and the environment^[1], such as the destruction of tourism resources and the degradation of environmental quality in tourist destinations^[2], mainly manifested as water pollution, air quality decline, and local ecological environment damage^[3]. Therefore, how to improve the efficiency of tourism resource utilization and environmental protection, reducing input and pollutant emissions, and achieve high-quality and sustainable development of the tourism industry are the challenges^[4].

Eco-efficiency was proposed by German scholars Schaltegger and Stum^[5] as an important indicator of resource and environmental efficiency, which can be used to explore the resource consumption and environmental effect of tourism in the process of creating tourism revenue, and measure a level of coordination between economic development and environmental protection. Ideally, the added value of the tourism economy is maximized, and resource consumption and environmental pollution are minimized^[6]. Existent studies about tourism eco-efficiency mainly focused on the definition of tourism eco-efficiency^[7,8], quantitative measurement^[9,10], influencing factors and mechanisms^[11,12], and related recommendations^[13,14]. Research methods mainly include Ecological Footprint^[15], Life Cycle Assessment^[16], Ecological Multiplier Measurement Model^[17], and Data Envelopment Analysis (DEA)^[18,19]. Most scholars used the radial angle DEA to calculate the directional distance function in their empirical studies to incorporate pollutant emissions into the efficiency evaluation framework^[20-22]. Driven by the actual demand for China's tourism and inspired by international tourism research, the research on the tourism eco-efficiency in China has received increasing attention and achieved many results in recent years. On the one hand, research topics have been expanding, from a focus on tourist hotels^[23] to various scopes such as the hotel industry^[24], travel agencies^[25], tourism transport^[26], tourism resources^[27], tourism environment^[28], and overall tourism development efficiency studies^[29-31]. On the other hand, research methods have been innovated, and the traditional efficiency measurement models used in the early stages have been gradually improved, such as the SORM-BCC super-efficiency model^[32], DEA-MI model^[33], and modified DEA model^[29], Bootstrap-DEA model^[34], and three-stage DEA model^[35]. In short, academic research

on tourism eco-efficiency has achieved certain results, but from the perspective of geography, the research on the spatial-temporal evolution of tourism eco-efficiency by spatial analysis methods still needs to be explored in depth.

Based on the super-efficiency SBM model, this study constructs a comprehensive evaluation model to measure the tourism eco-efficiency of 30 provinces in China from 2005 to 2020 (excluding Tibet, Hong Kong, Macao, and Taiwan due to data availability), explores the spatial-temporal evolution characteristics with the kernel density function, the standard deviation ellipse, and the center of the gravity model, and analyzes the influencing factors with the Tobit regression model. The purpose is to provide decision-making support to address resource efficiency issues and to realize the high-quality sustainable development of the tourism economy.

2. Methods and Data

2.1 Index System

The calculation of tourism eco-efficiency requires comprehensive consideration of resource consumption, environmental cost, and economic output. Based on relevant literature^[18,36-38], this study introduces two types of indicators, input and output, to construct a measurement index system (Table 1). The input indicators involve economic, resource, and environmental factors. Economic factors include labour force and capital investment. The labour force is measured by the total number of tourism employees, while the capital investment is measured by the number of star-rated hotels and the number of travel agencies. Resource factors include energy, water, and land resources. Considering the lack of statistical data, the consumption of land resources in tourism is measured by the weighted sum of the total number of A-level tourists attractions (i.e., one 1A destination weights 1, while one 5A destination weights 5), on the premise that the number of tourist destinations can reflect the input of land resources to some extent. Environmental factors include wastewater discharge, carbon emission, and solid waste disposal by the tourism industry. In terms of output, tourism revenue and the number of tourists are considered important indicators as they reflect the level of comprehensive development efficiency of the tourism industry. Note that this study does not consider the possible lagged effect of inputs on tourism efficiency.

2.2 Super-efficiency SBM Model

The super-efficiency SBM model was used to calculate

the tourism eco-efficiency. Firstly, the input and output indicators were integrated into four types of indicators, i.e., the economic input, the resource input, the environmental input, and the economic output. Then the entropy weight-TOPSIS method was adopted to process the indicators (assuming that there are n units to be evaluated, and each unit has m evaluation indicators).

Table 1. Evaluation index system of tourism eco-efficiency

Indicator type	Primary indicator	Secondary indicator (Unit)
Input indicators	Economic factors	Total number of tourism employees
		Number of star-rated hotels
		Number of travel agencies
	Resource factors	Tourism resource endowment
		Tourism energy consumption
		Tourism water consumption
	Environmental factors	Tourism wastewater discharge
		Tourism Carbon emission
		Tourism solid waste emissions
Output indicators	Economic outputs	Total tourism revenue
		Total number of tourists

The entropy method determines the weight ω_j of indicator j , and then a weighting matrix is constructed:

$$R = (r_{ij})_{n \times m}, r_{ij} = \omega_j \cdot x_{ij} \quad (1)$$

The optimal and the worst solution can be determined as follows:

$$S^+ = \max (r_{1j}, r_{2j}, \dots, r_{mj}) \quad (2)$$

$$S^- = \min (r_{1j}, r_{2j}, \dots, r_{mj}) \quad (3)$$

Then the Euclidean distance between the i -th evaluation unit and the optimal or the worst solution is calculated:

$$D_i^+ = \sqrt{\sum_{j=1}^m (S^+ - r_{ij})^2}, D_i^- = \sqrt{\sum_{j=1}^m (S^- - r_{ij})^2} \quad (4)$$

A comprehensive evaluation index can be calculated as follows:

$$C_i = \frac{D_i^-}{D_i^- + D_i^+} \quad (5)$$

If the production system has n decision-making units (DMU), and each unit includes four vectors, i.e., economic cost input, resource cost input, environmental cost input, and economic output, the efficiency analysis framework can be formed as follows:

$$T = (x^m, x^r, x^e, y^d) \quad (6)$$

where, $x^m \in R_+^{a \times n}$, $x^r \in R_+^{b \times n}$, $x^e \in R_+^{c \times n}$ and $y^d \in R_+^{f \times n}$ are data matrixes of economic cost input, resource cost input, environmental cost input, and economic output, respectively, and $a, b, c,$ and f represent the number of input and output

factors, respectively.

The production possibility frontier under variable returns to scale and weak disposability can be defined as:

$$P = \{(x^m, x^r, x^e, y^d) | x^m \geq \lambda X^m, x^r \geq \lambda X^r, x^e \geq \lambda X^e, y^d \leq \lambda Y^d, \lambda \geq 0\} \quad (7)$$

The super-efficiency SBM model with variable returns to scale is:

$$Min \rho = \frac{1 + \frac{1}{m} \sum_{i=1}^m s_i^- / x_{ik}}{1 - \frac{1}{q} \sum_{r=1}^q s_r^+ / y_{rk}} \quad (8)$$

$$\sum_{j=1, j \neq k}^n \lambda_j x_j - s_i^- \leq x_{ik} \quad (9)$$

$$\sum_{j=1, j \neq k}^n \lambda_j y_j - s_r^+ \geq y_{rk} \quad (10)$$

$$1 - \frac{1}{q} \sum_{r=1}^q s_r^+ / y_{rk} > 0 \quad (11)$$

$$\lambda, s^-, s^+ \geq 0 \quad (12)$$

$$\sum_{j=1, j \neq k}^n \lambda_j = 1 \quad j = 1, 2, \dots, n (j \neq k) \quad (13)$$

where, x and y represent input and output variables, respectively, m and q represent the number of input and output variables, respectively, s^- and s^+ represent slack variables of input and output, respectively, and λ is a weight vector. Based on the above linear programming, the inefficiency value of resource for Province I in period t is calculated. The efficiency loss of the resource input (IE_r), environmental input (IE_e), and economic output (IE_y) can be decomposed as follows:

$$IE_r = \frac{1}{b} \sum_{i=1}^b \frac{s_i^{r-}}{x_{ik}^r} \quad (14)$$

$$IE_e = \frac{1}{c} \sum_{i=1}^c \frac{s_i^{e-}}{x_{ik}^e} \quad (15)$$

$$IE_y = \frac{1}{f} \sum_{r=1}^f \frac{s_r^{d+}}{y_{rk}^d} \quad (16)$$

This study set the decisive goal as $g = (-x^m, -x^r, -x^e, +y^d)$. It means that this study aims to achieve optimal production conditions by reducing the economic input, resource consumption, and environmental cost while gradually increasing the economic output. Assume that the actual observation value of the decision-making unit $DMU0$ is (M, R, E, D) , where $M, R, E,$ and D represent economic input, resource consumption, environmental cost, and economic output, respectively. When $DMU0$ reaches the best production possibility frontier, its observed value is (M^*, R^*, E^*, D^*) . Then the terms of $IE_R = (R - R^*)/R$, $IE_E = (E - E^*)/E$, $IE_D = (D^* - D)/D$ are defined to represent the inefficiency of resource input, the inefficiency of environmental in-

put, and the inefficiency of economic output, respectively.

$$E_e = \frac{E^*/D^*}{E/D} = \frac{1 - (E - E^*)/E}{1 + (D^* - D)/D} = \frac{1 - IE_E}{1 + IE_D} \quad (17)$$

2.3 Kernel Density Estimation (KDE)

KDE is a non-parametric estimation method to estimate the probability density of random variables. Assume that x_1, x_2, \dots, x_n are independent and identically distributed sample points, and the probability density function is $f(x)$, then the probability density estimation equation of the random variable at point x is:

$$\hat{f}(x) = \frac{1}{Nh} \sum_{i=1}^n K \left[\frac{X_i - x}{h} \right] \quad (18)$$

where, $K(*)$ is the kernel function, N is the number of sample observations, and h is a bandwidth that affects the smoothness and deviation of the density curve.

2.4 Standard Deviation Ellipse (SDE) and the Center of Gravity Model (CGM)

SDE quantitatively describes the centrality, directionality, spreadability, and other characteristics of the spatial distribution of elements from a global and spatial perspective. It reveals the spatial distribution and temporal evolution of geographic elements^[39]. CGM solves the problem of spatial changes in regional attributes by depicting the concentrated and discrete trends of regional attributes and their time-varying offset trajectories. The calculation equations are as follows:

$$\bar{x} = \frac{\sum_{i=1}^n M_i X_i}{\sum_{i=1}^n M_i} \quad (19)$$

$$\bar{y} = \frac{\sum_{i=1}^n M_i Y_i}{\sum_{i=1}^n M_i} \quad (20)$$

where, (X_i, Y_i) is the center coordinate of the i -th region, and M_i is an attribute value of the tourism eco-efficiency.

2.5 Tobit Regression Model

In order to investigate the influencing factors of tourism eco-efficiency, a Tobit regression model was constructed by taking the influencing factors as explanatory variables and the efficiency value as an explained variable. The model can be expressed as follows:

$$Y = \begin{cases} Y^* = \alpha + \beta X + \varepsilon, & Y^* > 0 \\ 0, & Y^* \leq 0 \end{cases} \quad (21)$$

where, Y is a truncated dependent variable vector, X is an independent variable vector, β is an intercept term vector, α is a regression parameter vector, and ε is a disturbance term, $\varepsilon \sim N(0, \sigma^2)$. Since the dependent variable is discretely distributed, the parameters of the Tobit regression model would be biased and inconsistent if estimated by

Ordinary Least Square (OLS), so Maximum likelihood (ML) is used to estimate the parameters of the model.

2.6 Data Sources

Data were collected from the 2006-2021 China Statistical Yearbooks, China Tourism Yearbooks, China Energy Yearbooks, regional statistical yearbooks, and statistical bulletins. Some indicators were obtained from the official website of the Ministry of Culture and Tourism of the People's Republic of China (<https://mct.gov.cn/>).

3. Results

3.1 Spatial-temporal Evolution Characteristics

DEA-Solver Pro 8.0 software was used to calculate the tourism eco-efficiency of 30 provinces in China. Based on related research results^[36], this study divides China into high-efficiency regions ($\rho \geq 1$), relatively high-efficiency regions ($0.8 \leq \rho < 1$), medium-efficiency regions ($0.6 \leq \rho < 0.8$), and low-efficiency regions ($\rho \leq 0.6$) according to different levels of tourism eco-efficiency.

From Figure 1, the overall tourism eco-efficiency shows a fluctuating upward trend. The average efficiency index has increased from 0.602 in 2005 to 0.809 in 2020, indicating that the tourism eco-efficiency in China has increased from the medium-efficiency level to the relatively high-efficiency level, but has not yet reached the maximum production possibility frontier. This is mainly due to that the Chinese government put forward the concept of green development in the 13th Five-Year Plan, and governments at all levels lay their emphasis on how to take the lead in realizing the green development of tourism. This concept not only considers the regional tourism economic growth, but also pays attention to the environmental impact, and enhances the green evaluation of tourism by governments at all levels from the perspective of government governance, which is conducive to governments at all levels to formulate corresponding policies to guide the green development of tourism, thereby improving the tourism ecological efficiency. The average tourism eco-efficiency index in the eastern region was 0.872, which was significantly higher than those in the central and western regions. The tourism eco-efficiency level in the central region was higher than that in the western region has been continuously increasing since 2015 and reaching the maximum of 0.733 in 2020. However, there was still a large gap compared with the eastern region. Although the tourism eco-efficiency in the western region had been continuously improved, the overall level was still not high.

From Figure 2, the overall spatial pattern of tourism

eco-efficiency in China is high in the southeast and low in the northwest. The reason is that most of the southeast regions are tourism hot spots or highly developed regions with unique advantages in tourism ecological efficiency and tourism green innovation, which have realized the coupling and coordinated development of the two. The northwest region lays more emphasis on tourism economic benefits but pays less attention to the green ecological development of Tourism, and also lacks financial investment. Specifically, Tianjin and Guangdong are high-efficiency regions; Beijing, Shandong, Zhejiang, and Ningxia are relatively high-efficiency regions; and Anhui, Jiangsu, Heilongjiang, Shanghai, Hunan, Hainan, Fujian, Henan, Hubei, and Jilin are medium-efficiency regions. In 2010, significant improvements were observed in all provinces. Beijing, Liaoning, Jiangsu, Shanghai, and Hainan had evolved into high-efficiency regions. Henan, Chongqing, and Heilongjiang had stepped into the relatively high-efficiency category. Sichuan and Shaanxi had progressed

to the medium-efficiency level. In 2020, high-efficiency regions were generally distributed in southern China with a C-shaped distribution pattern, surrounded by relatively high-efficiency and medium-efficiency regions. The spatial agglomeration was obvious, mainly the high-efficiency agglomeration in the south and the low-efficiency agglomeration in the north.

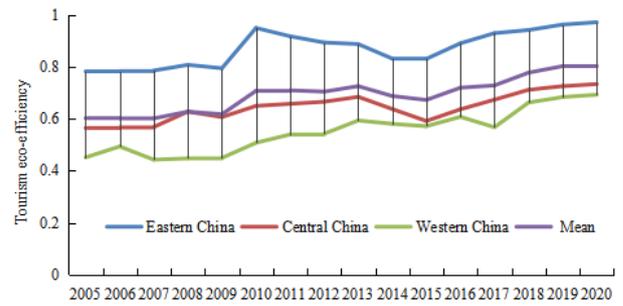


Figure 1. Trend of tourism eco-efficiency of China from 2005 to 2020

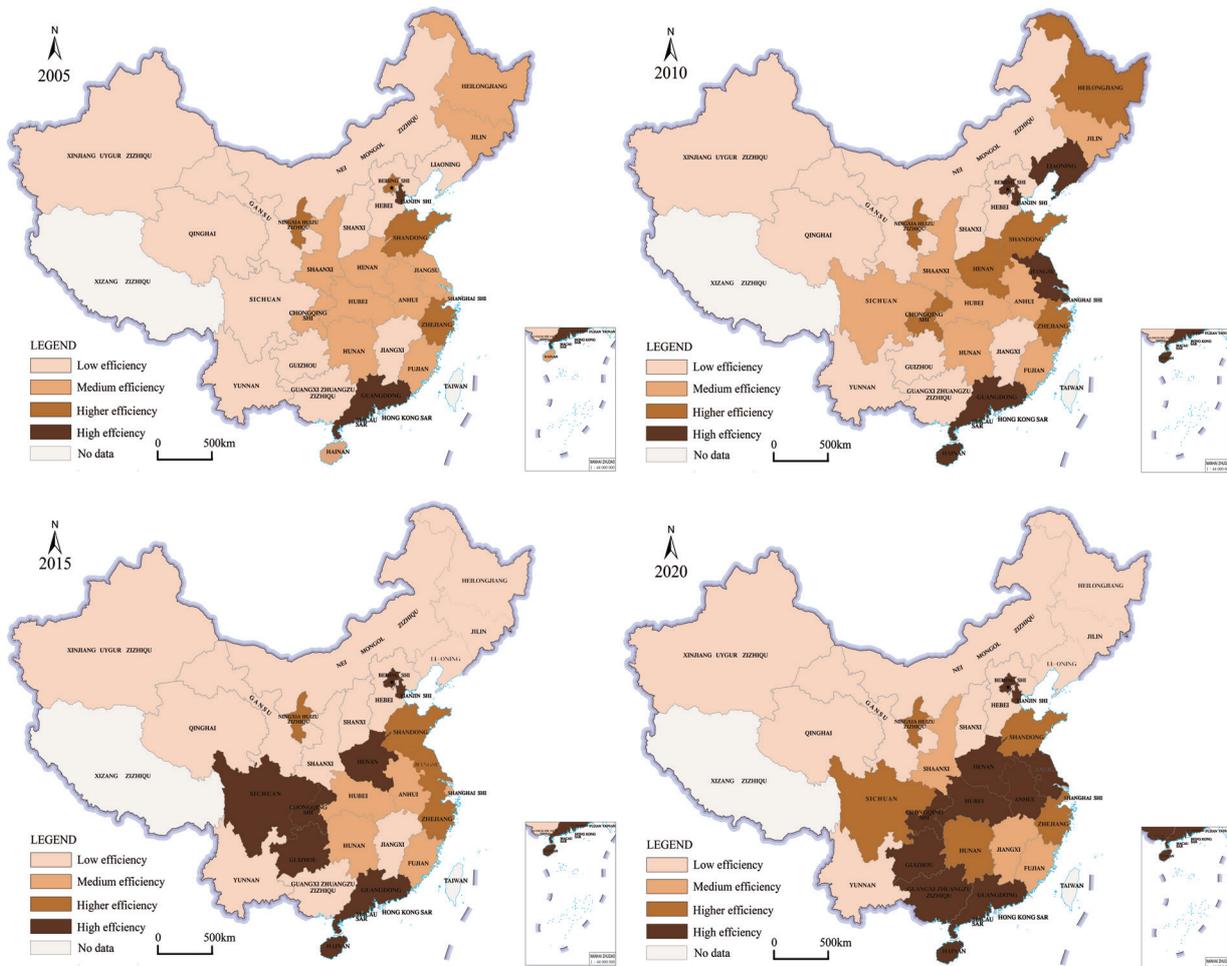


Figure 2. Spatial pattern of tourism eco-efficiency of China in 2005, 2010, 2015 and 2020

3.2 Analysis of Kernel Density Curve and Evolution of the Center of Gravity

From Figure 3, the Kernel density curves of tourism eco-efficiency from 2005 to 2020 show a unimodal-bimodal-unimodal evolution pattern, but with a trailing tail. In 2005, the tourism eco-efficiency corresponding to the highest value was maintained at a low level of about 0.5, and the curve had a right tail, indicating that the development in different provinces was remarkably imbalanced and the low-efficiency regions accounted for a relatively large proportion. In 2010, the highest efficiency value of the first wave was around 0.5, and the peak value of the second wave was around 0.9, indicating the existence of polarization and the significant difference between provinces. In 2015, the curve was weakened, with lower peaks and wider waves, indicating fewer inter-provincial variations. In 2020, the peak value further shifted to the right, the peak was higher, and the width became wider, indicating that the curve gradually transformed into a normal distribution. When the corresponding peak efficiency value increased to about 1.0, the diffusion effect in the eastern region and the late-development advantage in the western region with lower efficiency initially worked, which indicated that the tourism eco-efficiency was significantly improved, and the difference between provinces gradually became smaller.

The center of gravity of tourism eco-efficiency in China was at the junction of Henan and Hubei provinces, indicating that the tourism eco-efficiency in the eastern region was higher than that in the western region. From Figure 4, in 2005-2010, the center of gravity of the tourism eco-efficiency mainly shifted to the east from Pingdingshan City to Luohe City in Henan Province by a total of 52.842 kilometres; in 2011-2017, the center of gravity mainly shifted to the southwest by 231.14 kilometres, and came to Suizhou City, Hubei Province in 2017; in 2018-2020, the center of gravity moved northwards by 12.184 kilometres to the junction of Xiangyang City and Suizhou City in Hubei Province. Overall, the center of gravity of environmental efficiency moved to the southwest, from Henan to Hubei province, which indicated that the tourism eco-efficiency in the southern and western regions was improved faster than that in the northern and eastern regions.

3.3 Analysis of Standard Deviation Ellipse

From Table 2, the length of the minor axis of SDE

dropped from 788.72 km in 2005 to 762.29 km in 2020, indicating that the tourism eco-efficiency has been polarized in the direction of the minor axis. The changes in the length of the minor axis can be divided into two stages: from 2005 to 2013, the length continuously decreased from 976.91 km to 774.77 km, indicating that the tourism eco-efficiency at this stage was continuously polarizing; after 2013, the length remained stable and fluctuated at around 780 km, indicating that there was no significant change in the agglomeration of tourism eco-efficiency. Overall, the area of the eclipse showed a fluctuating decreasing trend. The shape index of the tourism eco-efficiency SDE decreased from 0.84 to 0.64 from 2005 to 2013. From 2013 to 2020, this shape index increased from 0.64 to 0.70, which suggested that the tourism eco-efficiency in all directions has become more and more balanced.

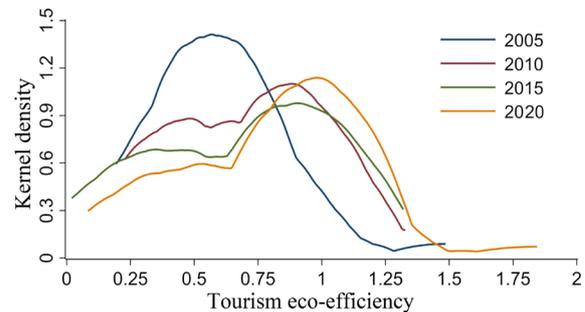


Figure 3. Trend of the kernel density curve of tourism resource efficiency of China

From the perspective of azimuth rotation, the azimuth angle of the tourism eco-efficiency SDE exhibited an M-shaped change. From 2005 to 2011, it increased from 22.671° to 25.866° . When rotating clockwise, it gradually approached the northeast-southwest direction, indicating a rapid improvement in the tourism eco-efficiency in the direction of “south-by-southeast” to “north-by-northwest”. During 2011-2012, the azimuth angle decreased to 23.999° , and the standard deviation ellipse rotated 1.877° counter-clockwise from northeast to southwest. During 2012-2014, the azimuth angle increased to 25.781° . After 2014, the fluctuation of the azimuth angle eased, and the azimuth angle dropped to 23.514° in 2020. Overall, the azimuth angle fluctuated greatly during the study period, but there was little change in 2020 compared to 2005, with only a slight increase of 0.843° , which indicated that in general, the tourism eco-efficiency evolved in a north-northeast to south-southwest pattern, with no significant change in the overall trend.

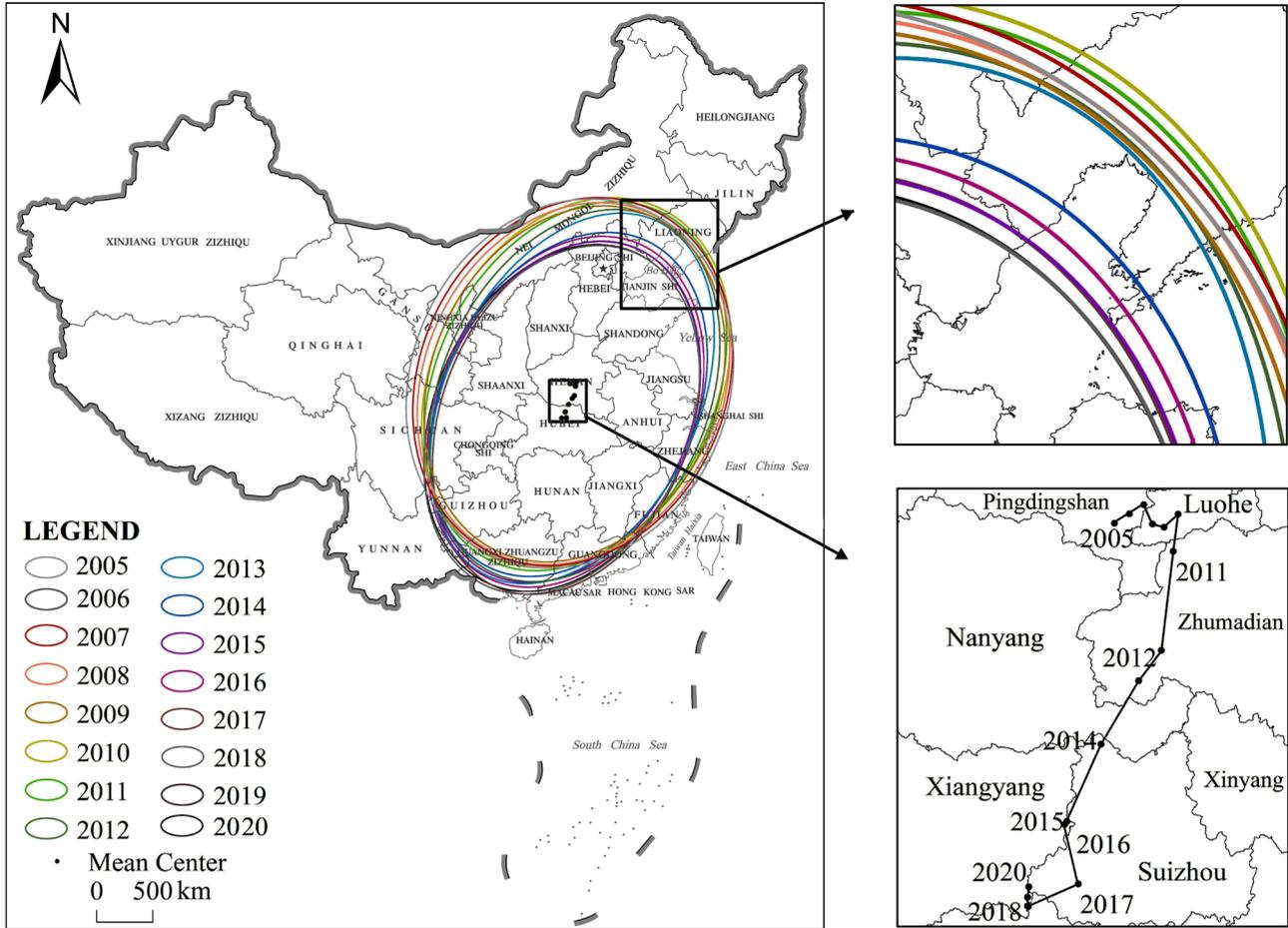


Figure 4. Shift of standard deviation ellipse and the center of gravity of tourism eco-efficiency

Table 2. Results of standard deviation ellipse parameters of the tourism eco-efficiency in China

Year	Major semi-axis(km)	Minor semi-axis(km)	Shape index	Area (km ²)	Azimuth An(°)
2005	1167.64	976.91	0.84	358.34	22.67
2006	1170.32	962.56	0.83	356.27	23.08
2007	1171.65	943.70	0.81	347.34	23.53
2008	1154.95	918.37	0.80	333.20	24.08
2009	1138.89	879.03	0.77	314.49	23.80
2010	1196.85	882.17	0.74	331.68	25.77
2011	1198.09	855.28	0.71	321.9	25.87
2012	1205.57	820.13	0.68	310.60	24.00
2013	1214.60	774.77	0.64	295.62	25.59
2014	1120.10	777.73	0.69	273.66	25.78
2015	1102.75	766.46	0.7	265.5	23.93
2016	1133.06	786.68	0.69	280.01	23.71
2017	1133.20	766.71	0.68	272.94	21.23
2018	1126.47	781.64	0.69	276.60	23.90
2019	1120.36	783.52	0.69	276.36	23.72
2020	1118.30	785.75	0.70	276.04	23.51

3.4 Influencing Factors of the Tourism Eco-efficiency in China

Referring to relevant literature ^[40-42], combined data availability, variables including economic development level, environmental regulation, economic openness, industrial structure, traffic condition, and locality were selected to establish a panel Tobit regression model to analyze the influencing factors of the tourism eco-efficiency in China.

$$\begin{aligned}
 Y_{it} = & \alpha_0 + \beta_1 \ln ED_{it} + \beta_2 (\ln ED_{it})^2 + \beta_3 ER_{it} \\
 & + \beta_4 OW_{it} + \beta_5 IS_{it} + \beta_6 IA_{it} \\
 & + \beta_7 (IA_{it})^2 + \beta_8 TC_{it} + \beta_9 L_{1it} + \beta_{10} L_{2it} + \varepsilon_{it}
 \end{aligned}
 \tag{22}$$

where, Y is tourism eco-efficiency, and ED is economic development level, measured by per capita GDP. To minimize the impact of heteroscedasticity, ED was processed by logarithm, and a quadratic term was introduced to verify the EKC theory. ER is environmental regulation, measured by the proportion of environmental governance investment in GDP, OW is economic openness level, measured by the proportion of FDI in GDP, IS is indus-

trial structure, measured by the proportion of tertiary industries, and IA is industrial agglomeration, measured by tourist location entropy. Because industrial agglomeration and resource efficiency are not linearly related, a quadratic term was introduced. TC is traffic condition, measured by highway density, L is locality, with $L1=1$ as the eastern region and $L2=1$ as the central region, $a0$ is a constant term, βn is a regression coefficient of variable n , and ϵ_{it} is an error term.

The Random Effect Panel Tobit Regression Model was used to analyze the influencing factors. From Table 3, all first-order coefficients of the logarithm of economic development level are positive, while all the quadratic coefficients are negative, which indicates that the tourism eco-efficiency has evolved in an inverted U-shaped curve, i.e., first rising and then declining. Currently, the efficiency in most provinces was on the rise, in line with the Environmental Kuznets Curve [43]. There is an U-shaped relationship between tourism eco-efficiency and the level of industrial agglomeration. Once the industrial agglomeration reaches a certain level, the industrial specialization and scale effect will promote the accumulation of tourism elements and the overflow of technological innovation, which will then produce agglomeration and radiation effects that can improve the tourism eco-efficiency [44]. Simultaneously, positive environmental externalities have emerged, the scale effect of environmental governance has gradually increased, the marginal cost of pollution control for enterprises in agglomeration regions has been reduced, and the tourism eco-efficiency has been effectively improved [45]. Environmental regulations have a significantly negative impact on tourism eco-efficiency. In this regard, it provides evidence in support of both the “compliance cost theory” and the “innovation compensation theory” [46]. It is also verified that the command-control environmental governance model characterized by environmental governance investment can reduce the ecological effect of investment in the absence of incentive mechanisms in environmental governance [47]. The economic openness coefficients are significantly positive, indicating that increasing openness is conducive to the improvement of efficiency. The industrial structure coefficients are all significantly negative with small absolute values, indicating that environmental governance for tertiary industries is more difficult compared to other industries because they generate more types of and more broadly distributed pollution [48]. The traffic condition coefficients are significantly positive, indicating that the improvement of traffic conditions can directly reduce transportation and travel costs. In the eastern region, the coefficients are not significant, while in the central region, they are all negative but at different

significance levels, which indicates that locality harms tourism eco-efficiency in central provinces.

Table 3. Tobit regression analysis results of tourism eco-efficiency

Influencing factors	Explanatory variables	Coefficient	Standard error	Z-statistics
Economic development level	$\ln(ED)$	1.352***	0.476	2.84
	$\ln^2(ED)$	-0.061***	0.023	-2.59
Environmental regulations	ER	-0.055***	0.017	-3.3
Economic Openness	OW	0.189***	0.057	3.33
Industrial structure	IS	-0.006***	0.002	-2.9
Industrial agglomeration	IA	-0.435***	0.099	-4.39
	$IA2$	0.138***	0.033	4.18
Traffic condition	TC	0.595***	0.098	6.1
Locality	$L1$	-0.135	0.116	-1.17
	$L2$	-0.200*	0.12	-1.67
Constant	$a0$	-6.674***	2.434	-2.74

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

4. Conclusions and Discussion

This study measured the tourism eco-efficiency of 30 provinces in China from 2005 to 2020 and analyzed its spatial-temporal characteristics as well as its influencing factors. The results showed that the tourism eco-efficiency in China generally fluctuated and raised, but has not yet reached the maximum production possibility frontier. Regarding the evolutionary trend, the Kernel density curve showed an unimodal-bimodal-unimodal pattern, while inter-provincial differences have been decreasing and becoming more balanced. The center of gravity of tourism eco-efficiency was located at the junction of Henan and Hubei provinces. The center of gravity of tourism eco-efficiency generally shifted to the south-southwest from Henan to Hubei province, indicating that the tourism eco-efficiency in southern and western regions improved faster than in northern and eastern regions. Based on the SDE analysis, both the major and minor axes showed a shrinking trend, and the area of the eclipse was continuously decreasing, indicating that the spatial agglomeration of tourism eco-efficiency became more and more significant. In terms of influencing factors, there was a significant inverted U-shaped relationship between economic development level and tourism resources. Increasing

the level of economic openness and the optimization of traffic conditions can help improve tourism eco-efficiency. The industrial structure, environmental regulation, and locality had negative but limited effects on tourism eco-efficiency.

Eco-efficiency is the core indicator to promote the high-quality development of tourism, reflecting the resource and environmental cost of creating a certain economic output in the process of tourism development, which can be used to measure whether tourism economic development is environmentally friendly^[49]. The higher the eco-efficiency, the more coordinated the development of the tourism economy and the environment, and the higher the level of resource utilization. Therefore, the tourism eco-efficiency should be comprehensively evaluated and its influencing factors should be analyzed. In recent years, the rapid development of the tourism economy in provinces has increased non-desired output and a large amount of inefficient output, leading to the tourism eco-efficiency in provinces being lower than that in south-east coastal areas. It is crucial to construct a reasonable evaluation model of tourism eco-efficiency, especially in the critical period of economic transformation. Based on the study and analysis of the spatial characteristics of China's tourism eco-efficiency and its influencing factors, this study objectively evaluated the differences in tourism eco-efficiency among provinces in China, which is helpful for policymakers to identify the main problems and take targeted measures^[50], and is of great practical significance to promote the high-quality development of tourism. In addition, the findings of this study are consistent with the existing studies^[51,52,53], and strengthen the spatial analysis of tourism eco-efficiency, which can provide scientific reference for tourism spatial governance and optimization. For the sustainable and coordinated development of tourism, it is also necessary to analyze the causes of tourism environmental problems, the modes of impact, and the caused results, hoping to provide services for the management and decision-making of tourism development^[54]. Notably, the causes of environmental damage and degradation of environmental quality in tourism areas are multiple, and human economic behaviour is one of the most important factors^[55].

To advance the tourism eco-efficiency to reach the maximum production possibility frontier, and narrow the gap between the eastern, central, and western regions, the following policy recommendations are proposed. First, the eastern region can give full play to its leading edge, further increase the investment in tourism ecological protection and governance, and improve the high-tech application and resource allocation capacities. The

eastern region's exemplary and leading role can facilitate tourism development in the central and western regions. Meanwhile, the central and western regions can exert the late-development advantage by fully tapping their potentials, actively learning from the eastern high-efficiency regions about tourism development concepts, technologies, and experiences, innovating green and low-carbon technologies, and promoting ecotourism with the construction of ecological civilization as the mainline. Second, rationally introduce foreign direct investment (FDI), adhere to both quantity and quality, diversify tourism development, promote the upgrading of tourism consumption, and focus on introducing advanced environmental protection and innovative technologies in tourism development. Third, perfect the tourism infrastructure, improve traffic networks, enhance transport capacity, and promote the openness and collaboration of the intra- and inter-regional tourism industry. Fourth, improve the institutional arrangement for environmental governance, promote the transformation of environmental regulation from "regulating" to "governing", mobilize relevant tourism enterprises to actively participate in environmental governance, and enhance environmental protection awareness to facilitate the transformation of the tourism industry into a resource-saving and environment-friendly industry.

Conflict of Interest

There is no conflict of interest.

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