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Research Article

Temporal and Spatial Evolution of Public–Private Partnership (PPP) Project Risks in China: 2003–2019

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The implementation of public–private partnership (PPP) is perturbed by multiple factors, and it is difficult for the Chinese government to fully control the risks of PPP projects. Based on the DPSIR model, this study constructed the PPP projects risk evaluation index system by using the TOPSIS method. Then the spatial variation, standard deviation ellipse, and gray dynamic model were used to analyze the spatial–temporal dynamic evolution characteristics of the risk level of PPP projects from 2003 to 2019 and to make reasonable predictions of the future spatial distribution pattern. This study yielded the following five results: (1) the average risk level of China's PPP projects is 0.722, with a decreasing trend of fluctuation and relatively stable risk; (2) high-risk provinces for PPP projects decrease, medium-risk provinces increase; (3) the spatial variability of risk is increasing, and the spatial differentiation is significant, showing a spatial evolution pattern of "west > central > east," but areas with low-risk values are clearly migrating to the east; (4) the spatial distribution pattern of risk has a north-easterly orientation, with a "north-west to north-east" trend in the path of movement; (5) There are differences in the spatial distribution patterns in the east–west and north–south directions, and the spatial spillover effect is not obvious. Based on the above results, the risk center of China's PPP projects will be shifted to the northeast in 2025–2035. Our study captures the evolution of PPP project risks in China in both temporal and spatial dimensions, which can provide lessons for optimizing global PPP project risk management.

1. Introduction

In recent years, public–private partnership (PPP) has gradually become an important way for China to promote supply-side structural reform and increase the supply of infrastructure services. As of December 31, 2021, China's Ministry of Finance filed 13,228 PPP projects, with a total investment of 3.33 trillion USD [1]. From 2014 to the end of 2022 Q3, the total number of China's PPP projects in the database reached 10,331, with a total investment of 2.53 trillion USD [2]. Among them, in 2016 Q3, the net investment of PPP projects in a single quarter reached 0.29 trillion USD. Since then, net investment has declined each year to a low of 0.21 trillion USD by 2022 Q2 [3]. Since 2014, when PPP projects were promoted in China, there has been an explosive growth of PPP projects in China, which has brought more and more problems to the standardized operation of the project [4]. Under this condition, China's Ministry of Finance began to issue a series of documents to regulate the operation of PPP projects, vetoing a considerable number of noncompliant PPP projects. During 2018 alone, 2,557 projects were rejected, representing 69.11% of the projects returned to the Ministry of Finance in the last 3 years (2016–2018) [5]. But since then, the number of projects retired from the project pool has decreased year by year. In 2016 Q2, the number of new PPP projects was 1,564, while it dropped to 151 in 2022 Q3 [3]. These figures reflect China's difficulties in successfully implementing PPP projects. In addition, given China's special national conditions, the imbalance and insufficiency of development among provinces and regions remains an important long-term issue that restricts the high-quality development of PPPs [6].

Therefore, it is necessary to analyze and forecast the risk level of China's PPP projects. Based on the prediction results, some risk prevention and control measures can be taken to ensure the smooth implementation of the PPP projects and reduce its potential losses. Existing studies are more mature in discussing the development characteristics of PPP projects and the factors affecting them [7, 8], but they ignore the changes that occur in time and space in the risk of PPP projects due to external objective causes. Therefore, This study integrates the theories and methods of geography, economics, and physics and focuses on the evolution of PPP project risks in China from both temporal and spatial perspectives based on a large-sample database utilizing panel data of 31 provinces in China from 2003 to 2019. This study contributes to the body of knowledge in two ways: (1) This study innovatively introduces the DPSIR model into the field of PPP projects risk research, further utilizes the model to construct a PPP projects risk indicator system, and employs econometric methods to quantitatively analyze the overall level of China's PPP project risks, regional differences, and the future development trend, thus revealing the important role of spatial–temporal evolution of PPP project risks in the important role in China's PPP projects risk management. (2) This is a pioneering study that explores the evolution of PPP project risks in China based on the combined temporal and spatial perspectives. At the same time, we clarify the development trend of PPP project risks in China, enrich the existing literature on PPP project risk management, and provide scientific references for the sustainable development of PPP in China.

The structure of the paper is as follows: the first part is the background introduction of the article; the second part is the literature review, which provides a detailed introduction of the PPP project risk development status and existing problems; the third part is the research design, which consists of the evaluation index system of China's PPP projects risk system based on DPSIR, and an introduction of the research methods and data sources of this paper; the fourth part is the demonstration analysis, through a characteristic analysis of PPP projects risk time series evolution, carrying on the reasonable forecast to its future spatial distribution pattern; the fifth part is discussion; the sixth part is the conclusions and the recommendations.

2. Literature Review

2.1. Research Status of PPP Projects. The development history of PPP in China has experienced six stages: the exploration stage from 1984 to 1993, the small-scale pilot stage from 1994 to 2002, the development stage from 2003 to 2008, the short-term stagnation stage from 2009 to 2013, the promotion stage from 2013 to the first half of 2017 and the clean-up and standardization stage from the second half of 2017 to the present [9]. By combing through the relevant cases and literature on PPP projects in China, it was found that China's PPP projects industry have experienced the transition from traditional infrastructure to the "Belt and Road"; rural revitalization to today's ecological PPP and green PPP; therefore, ecological and environmental protection is expected to become a hotspot for subsequent research in the field of PPP [10]. In terms of the content of PPP projects, it has gradually expanded from pricing measurement, investment evaluation, and financing to deeper issues such as risk management and control [11], performance incentives [12], and exit mechanisms [13]. From the perspective of research, PPP projects has extremely important practical value in the field of infrastructure construction in China. With the deepening of research, PPP has become a hot topic in Chinese academic communities, involving a variety of disciplines such as finance, law, engineering, and management [14]. PPP projects also play a key role in different fields. First, from a sustainability perspective, PPP projects are the most effective way to achieve sustainable development in the energy field [15]. Furthermore, given the economic, social, and environmental aspects, the PPP model is then also considered to create a sustainable environment [16]. In the research on the evaluation index of PPP projects, scholars generally use the following two evaluation index systems: First, the PPP project is refined to specific indicators from the three dimensions of the government sector, the private sector, and the public [17]; Second, the PPP project life cycle was analyzed through the five stages: project identification, preparation, procurement, implementation, and handover [18]. In terms of research on PPP project methods, qualitative research was the main method before 2019. The evaluation and measurement methods used by scholars were different, mainly including the fuzzy comprehensive evaluation method [19], QCA [20], improved TOPSIS method [21], gray correlation method [22], and VFM [23]. There are also qualitative and quantitative methods, such as improved matter-element method [24], Monte Carlo simulation [25], and entropy weight method [26]. At present, these studies systematically represent the scope of PPP research in China. However, few reports in these literatures pay attention to the temporal and spatial evolution of PPP project risks in China, which is crucial for the Chinese government and enterprises to manage PPP projects.

2.2. Evolution and Analysis Status of the Spatial Pattern of PPP Projects. In terms of analyzing the evolution of spatial patterns, in 2007, Chan et al. [27] paid attention to the regional differences in the drivers of PPP projects in mainland China and Hong Kong through an empirical questionnaire survey and found that the obvious differences between the two regions may be related to the different stages of socioeconomic development and needs. By analyzing the evolution of PPP in China from 1993 to 2010, Mu et al. [28] found the important driving factors of the domestic PPP model were the political, cultural, and institutional environment and proposed the spatial–temporal heterogeneity of the PPP model can be explained and analyzed from the perspective of path dependence. Cheng et al. [7] studied the spatial–temporal evolution of PPP projects under regional differences through the PPP project database of China and pointed out that the characteristics of spatial–temporal heterogeneity are related to factors such as the power of economic development, the influence of national policies, the preference and capacity of local governments, project feasibility and management, etc.

Chen [29] calculated the input–output efficiency of infrastructure investment by using stochastic frontier analysis and evaluated the economic sustainability and efficiency of PPP with a sample of 31 provinces in China from 2003 to 2018. Based on the Annual Survey of Industrial Firms in China during 1998–2009, Rudai studied the dynamic changes of Chinese manufacturing enterprises in TFP, and found that PPP projects have significantly promoted the growth of total factor productivity of enterprises [30]. These studies focus on the spatial autocorrelation of different time periods, lacking the analysis of regional differences and trends, and researchers have paid little attention to the prediction of PPP project risk levels.

2.3. Literature Review of Risk Management. In the field of project management, improper risk management has been identified as a major obstacle to the success of projects [31], and many researchers have pointed out the importance of recognizing and controlling the risks of infrastructure projects. Carbonara et al. [32] identified a list of major risks of PPP highway projects and their effective allocation and appropriate mitigation strategies through the results of a Delphi survey. Xiong et al. [33] proposed an ex-post risk management model and discussed in detail the ex-post risk countermeasures in concession renegotiation and early termination based on the risk assessment of PPP projects. Shijun [34] conducted risk management of large-scale international projects through computer modeling and simulation techniques, emphasized the importance of risk management decisions and pointed out the main problems and countermeasures in risk management of international projects. Shrestha et al. [35] used a structured questionnaire to investigate the risk allocation of PPP water conservancy projects in China and pointed out that the unreasonable risk allocation between the government and private sector is the main factor affecting the improper risk management of PPP water conservancy projects in China. Although a lot of research has been done on the risk management of PPP projects in China [36], the project risks have not been properly managed, which has directly led to the failure of most PPP projects. For example, after the PPP exit policy was introduced at the end of 2017, it directly involved the exit of 1,160 PPP projects [13]. Furthermore, although these studies have investigated the level of PPP project risk as a key aspect of optimizing PPP project risk management in China, these studies are not without limitations. In research design, most studies use a single PPP case study or economic modeling technology to evaluate PPP project risk. Furthermore, there are few studies that use a large amount of sample data, and these studies lack long-term, large-scale monitoring data to evaluate the level of PPP project risks, which is not conducive to systematic research on the evolution and management of PPP project risks in China. In order to better control PPP project risks, it is necessary for scholars to strengthen the research on regional PPP project risk time series.

Above all, this study constructs an evaluation index system for the risk level of China's PPP projects based on the DPSIR model by combing the above PPP-related studies, calculates China's PPP projects risk index based on the entropy value TOPSIS method since 2003, and evaluates China's PPP projects by using spatial variation model and standard deviation ellipse model. This study explores the spatial differentiation and evolution characteristics of PPP project risk level and predicts the future spatial distribution pattern with the help of the gray dynamic model, which provides a scientific reference for the sustainable development of PPP.

3. Research Design

3.1. Construction of the Evaluation Index System. The DPSIR model was established by the European Environment Agency in 1993 based on the PSR and DSR framework, and it has been widely used in the field of ecological risk research owing to its comprehensive and logical advantages [37]. PPP projects involve numerous interest groups, with different stakeholders pursuing different objectives. However, their basic objective is to facilitate the rapid formation and development of infrastructure and to meet the objectives of different interest groups. In addition, there are great similarities between the risk assessment of PPP projects and the state assessment of the natural environment [38]. First, both of them are systems that use a systematic perspective to solve problems; therefore, their system principles are consistent. Second, both of them are affecting the indicators in the whole system through the action of human socioeconomic production activities. The risk level of PPP projects can affect people's operation and management; people's evaluation and investment of PPP projects (such as value for money evaluation, financial affordability evaluation, and financial investment.) will also affect the risk level [39]. Finally, PPP follows the causal chain of the DPSIR. The PPP project risks system is regarded as a broad environment, and there is a causal relationship between each influencing factor and the risk assessment.

In this model, the "Driving force" (D) as the "origin" of the evolution of the PPP risk system, which is a potential cause of changes in the risks of the PPP project, reflecting the basic situation of local social economy and industrial growth. "Pressure" (P) refers to the advancement and reliability of technology generated by driving force, resource consumption intensity, environmental impact, political environment, public and private sector funds, comprehensiveness of risk identification, and rationality of risk sharing. "Status indicator" (S): Under the above pressures, the current status of the project is characterized by inadequate laws that make it difficult to operate the project and little government support. "Impact index" (I): in the process of PPP project operation, various states have an impact on the whole social system in terms of whether or not government officials are corrupt and the credibility of government and social capital. "Response index" (R): countermeasures are taken to improve and enhance the operation level of PPP projects, such as improving competitiveness, reducing market prices, meeting market demand, and other active coping strategies. The response provides a significant boost in driving force, creating a "closed loop" of the system. It can also be used to slowly relieve the pressure and improve the state, improving the

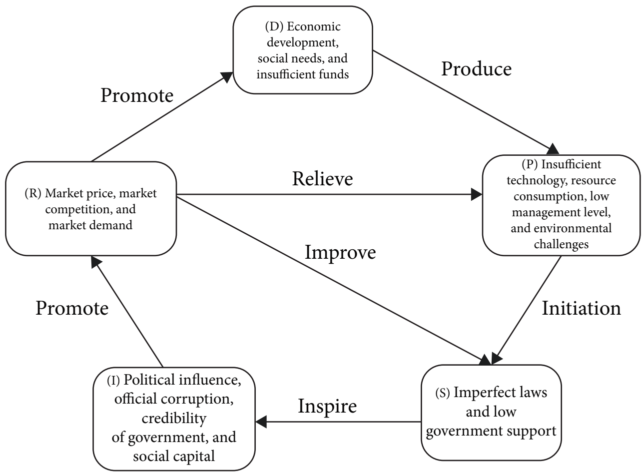

FIGURE 1: The DPSIR conceptual model of the PPP risk system D: driving force; P: pressure; S: state; I: impact; R: response.

overall situation of China's PPP projects risk system. Researchers can introduce the idea of DPSIR system analysis into the construction of the current PPP projects index system. They could screen and classify indicators from five levels: "Driving force" (D), "Pressure" (P), "Status" (S), "Impact" (I), and "Response" (R) and establish a systematic risk evaluation index system, as shown in Figure 1.

On the basis of model construction, researchers can combine the availability of data to follow the principles of systemic, hierarchical, and scientific, refining specific evaluation indicators from the survival and development status and interaction characteristics of the four subsystems of "state–society–enterprise–public." By analyzing the connotation and indicator form of the model, this study constructed an evaluation indicator system for China's PPP projects risk system (Table 1).

3.2. Classification Criteria of Evaluation Grades. So far, no unified risk assessment standard for PPP projects has been formed. Combining the existing research results and the actual situation, the proximity interval of [0, 1] is divided into five equal scores in accordance with the "equal score principle," which corresponds to the risk evaluation level of the PPP project, respectively (Table 2) [56].

3.3. Research Methodology

3.3.1. Entropy Weight TOPSIS Method. The entropy weight TOPSIS method consists of the entropy weight method and TOPSIS method. It is a suitable analysis method according to multiple indexes and has the advantages of being real, reliable, and intuitive [57]. Therefore, the paper evaluates the risk level of PPP projects in China as follows:

(1) Standardize the evaluation indicators;

$$y_{ij} = \frac{x_{ij} - \min_i x_{ij}}{\max_i x_{ij} - \min_i x_{ij}}, \tag{1}$$

$$y_{ij} = \frac{\max_i x_{ij} - x_{ij}}{\max_i x_{ij} - \min_i x_{ij}}, \tag{2}$$

$$p_{ij} = y_{ij} / \sum_{i=1}^{m} y_{ij}. \tag{3}$$

Formula (1) is used when the indicator is positive, and Formula (2) is used when the indicator is negative, $\max_i x_{ij}$, $\min_i x_{ij}$ are the maximum and the minimum value of the indicators, respectively.

(2) Construct the weighted standardized e_j decision matrix;

$$ej = -k \sum_{i=1}^{m} p_{ij} \ln p_{ij} \quad (k = 1/\ln m; j = 1, 2, \ldots n). \tag{4}$$

(3) Calculate the weight;

$$h_j = 1 - e_j \; (j = 1, 2, \ldots, n), \tag{5}$$

$$w_j = h_j / \sum_{j=1}^{n} h_j \; (j = 1, 2, \ldots, n). \tag{6}$$

(4) Determine the positive and negative ideal solution;

$$\begin{aligned} d_i^{+} &= \sqrt{\sum_{j=1}^{n} w_j \left(pij - a_j^{+}\right)^2}; \\ d_i^{-} &= \sqrt{\sum_{j=1}^{n} w_j \left(p_{ij} - a_j^{-}\right)^2} \; (i = 1, 2, \ldots m), \end{aligned} \tag{7}$$

a_j^{+} and a_j^{-} are the maximum and minimum values of the standardized indicators, respectively.

(5) Calculate the distance between positive and negative ideal solutions;

$$C_i = \frac{d_i^{-}}{d_i^{+} + d_i^{-}} \; (i = 1, 2 \ldots, m). \tag{8}$$

(6) Calculate the proximity between each scheme and the ideal solution in descending order [58]. As the score approaches 0–1, the value is inversely proportional to the risk level.

3.3.2. Spatial Variation Model. The space deterioration function, also known as the semivariation function, is an effective means of analyzing spatial variation law and structure analysis. This paper uses this model to reveal the evolution law of the risk spatial pattern of PPP projects in China. Kriging interpolation is a simulation of spatial modeling and interpolation of stochastic processes based on the spatial variation model [59]. Inserting space in a specific finite region, the Kriging method gives optimal linear unbiased estimates with functional expressions as follows:

Table 1: Risk index system of PPP project (positive and negative perspective).

The standard layer	First-level elements	Secondary elements	Indicator form	Index unit	Indicator attribute	Reference documentation
Driving force	Economic risk	Local economic situation	GDP	Billions of dollars	Forward direction	[40]
		Local fiscal situation	Fiscal and public budget revenue	Billions of dollars	Forward direction	[41]
Driving force	Financial risk	Government debt	Bank loan balance	Billions of dollars	Backward direction	[42]
		Financing situation	Total investment of PPP project	Billions of dollars	Opposite direction	[43]
Pressure	Ecological risk	Ecological environment governance	Total investment of pollution control	Billions of dollars	Backward direction	[44]
Pressure	Technical risk	Technological level	R&D funds	10,000 dollars	Forward direction	[45]
Pressure	Management risk	Management capability	Level of higher education received	Number of people	Forward direction	[46–48]
		Efficiency of the administrative system	Government efficiency	%	Forward direction	[49]
State	Social risk	Public health emergency of international concern	Value added of administrative review and administrative appeal cases	Number of packages	Backward direction	[50]
State	Natural disaster risk	Losses caused by events of force majeure	Direct economic losses caused by natural disasters in that year	Billions of dollars	Backward direction	[51]
Impact	Political risk	Corruption	Duty crime + corruption	Number of people	Backward direction	[52]
Impact	Credit risk	Government credit	Staffing changes for public officials	Thousands of people	Backward direction	[53]
		Social capital credit	Number of enterprises discredited	Number of packages	Backward direction	[54]
Response	Market risk	PPP market competition	Number of PPP projects	Individual	Backward direction	[55]
		Raw material price volatility	Building materials price index	%	Backward direction	[50]

Table 2: Risk evaluation grade of PPP project.

Close degree	[0, 0.2]	(0.2, 0.4]	(0.4, 0.6]	(0.6, 0.8]	(0.8, 1]
Risk status	Low risk	Medium-low risk	Medium risk	Medium-high risk	High risk
Risk level	I	II	III	IV	V

$$Y(x_0) = \sum_{i=1}^{n} \delta_i Y(x_i). \tag{9}$$

In the preceding formula, $Y(x_0)$ is the unknown point; $Y(x_i)$ is the known sample point; δ_i is the weight of the first sample point to the unknown point; n is the number of known points.

3.3.3. Standard Deviation Ellipse Model. The standard deviation elliptic model is a spatial statistical method that can accurately evaluate the overall characteristics of object spatial distribution. This paper introduces this method to present the spatial distribution direction characteristics of PPP project risks in China. The standard deviation ellipse includes four basic elements: center, long axis, short axis, and corner. Among them, the central point indicates the relative position of the evaluated elements, the long and short axes indicate the degree of dispersion of the elements in the major and minor directions, respectively, and the angle indicates the direction of the main trend of development. The specific calculation formula is shown in the study of Gai et al. [60].

$$\overline{X}_w = \frac{\sum_{i=1}^{n} w_i x_i}{\sum_{i=1}^{n} w_i}; \overline{Y}_w = \frac{\sum_{i=1}^{n} w_i y_i}{\sum_{i=1}^{n} w_i}. \tag{10}$$

X axis standard deviation:

$$\sigma_x = \frac{\sqrt{\sum_{i=1}^{n} (w_i \overline{x_i} \cos\theta - w_i \overline{y_i} \sin\theta)}}{\sum_{i=1}^{n} {w_i}^2}. \tag{11}$$

Y axis standard deviation:

$$\sigma_y = \frac{\sqrt{\sum_{i=1}^{n} w_i \overline{x_i}} \sin\theta - w_i \overline{y_i} \cos\theta}{\sum_{i=1}^{n} {w_i}^2}. \tag{12}$$

3.3.4. Gray Prediction.

(1) GM (1, 1) Model. The gray GM (1, 1) model can preprocess the raw data to obtain better smoothness, making the prediction more efficient. Owing to the limitation of data sample size, this paper predicts the five parameters of center longitude x_1, latitude x_2, long axis x_3, short axis x_4, and rotation angle x_5 with the gray GM (1, 1) model, so as to explore the future evolution of the spatial pattern of PPP project risks in China.

3.4. Data Source. This paper is only focused on Chinese mainland provinces. Hong Kong, Macao, and Taiwan of China are outside the scope of this study. According to the development history of PPP in China, the exploration of PPP began in the 1980s [7], and before 2003, there were a lot of statistical records on the official website, and the PPP index data from 2020 to 2022 has not been updated yet. In order to fully ensure the objectivity of the research process and the accuracy of the findings, this study selected the years from 2003 to 2019. The data involved in this paper are mainly derived from the China Statistical Yearbook of 2003–2019, China City Statistical Yearbook, China Environmental Statistical Yearbook, World Bank PPI Database, BRI data, Wind database, RESSET database, Ministry of Finance website, China Public Private Partnerships Centre, and so on. Small amount of provincial local government data are supplemented by the linear interpolation method.

4. Empirical Results

4.1. Evolution Characteristics of PPP Project Risks Time Series. Based on geographic factors, we divided the study sample into three regions: the eastern (Beijing, Tianjin, Hebei, Liaoning, Shanghai, Jiangsu, Zhejiang, Fujian, Shandong, Guangdong, Guangxi, and Hainan), the central (Shanxi, Inner Mongolia, Jilin, Heilongjiang, Anhui, Jiangxi, Henan, Hubei, and Hunan) and the western (Chongqing, Sichuan, Guizhou, Yunnan, Tibet, Shaanxi, Gansu, Qinghai, Ningxia, and Xinjiang) [61]. Based on the entropy weight TOPSIS method, the comprehensive risk index of PPP projects in China's provinces and municipalities from 2003 to 2019 is calculated. We drew the corresponding line graphs (Figures 2 and 3) and box plots (Figure 4) to intuitively reflect the time series evolution characteristics of PPP project risks.

In general (Figure 2), from 2003 to 2019, the comprehensive risk index of PPP projects in China increased from 0.7346 in 2003 to 0.7668 in 2010 and then decreased to 0.7157 in 2019. The risk level was at the medium-high-risk level from 2003 to 2019. China launched a 4-trillion-RMB plan, and banks provided unconditional loans in 2008 [62]. PPP projects were thus greatly stimulated. As a result, the risk of PPP projects increased slightly in 2008 and peaked at 0.7668 in 2010.

PPP projects were not widely implemented in China for economic, policy, and environmental reasons before 2013. Since 2013, the government has made great efforts to introduce PPP projects to alleviate the pressure of local finance. The government successively formulated policy documents such as "Notice on Printing and Distributing the Operation Guide of the Cooperation Mode between Government and Social Capital" (for trial implementation), and the corresponding investment has increased year by year. PPP project risks showed medium-high risks in 2013. According to the website "Government and Social Capital Cooperation Centre of Ministry of Finance," the number of PPP projects has gradually increased since 2014. From 2014 to 2017, the risk

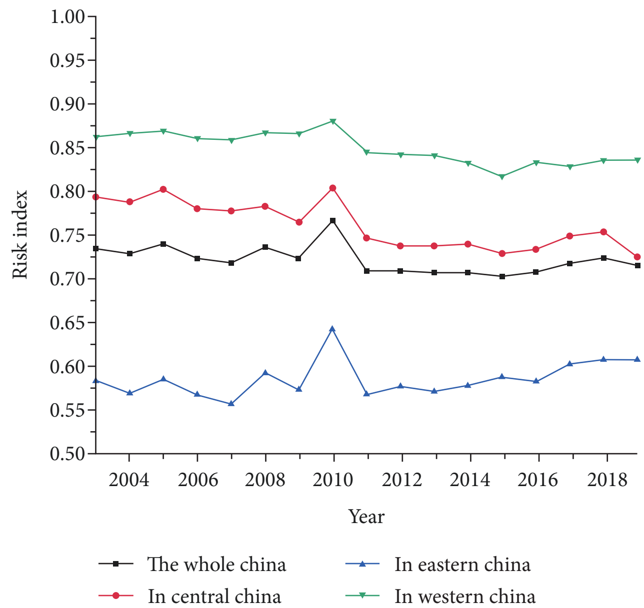

FIGURE 2: Trends of PPP projects risk level in China's subregions.

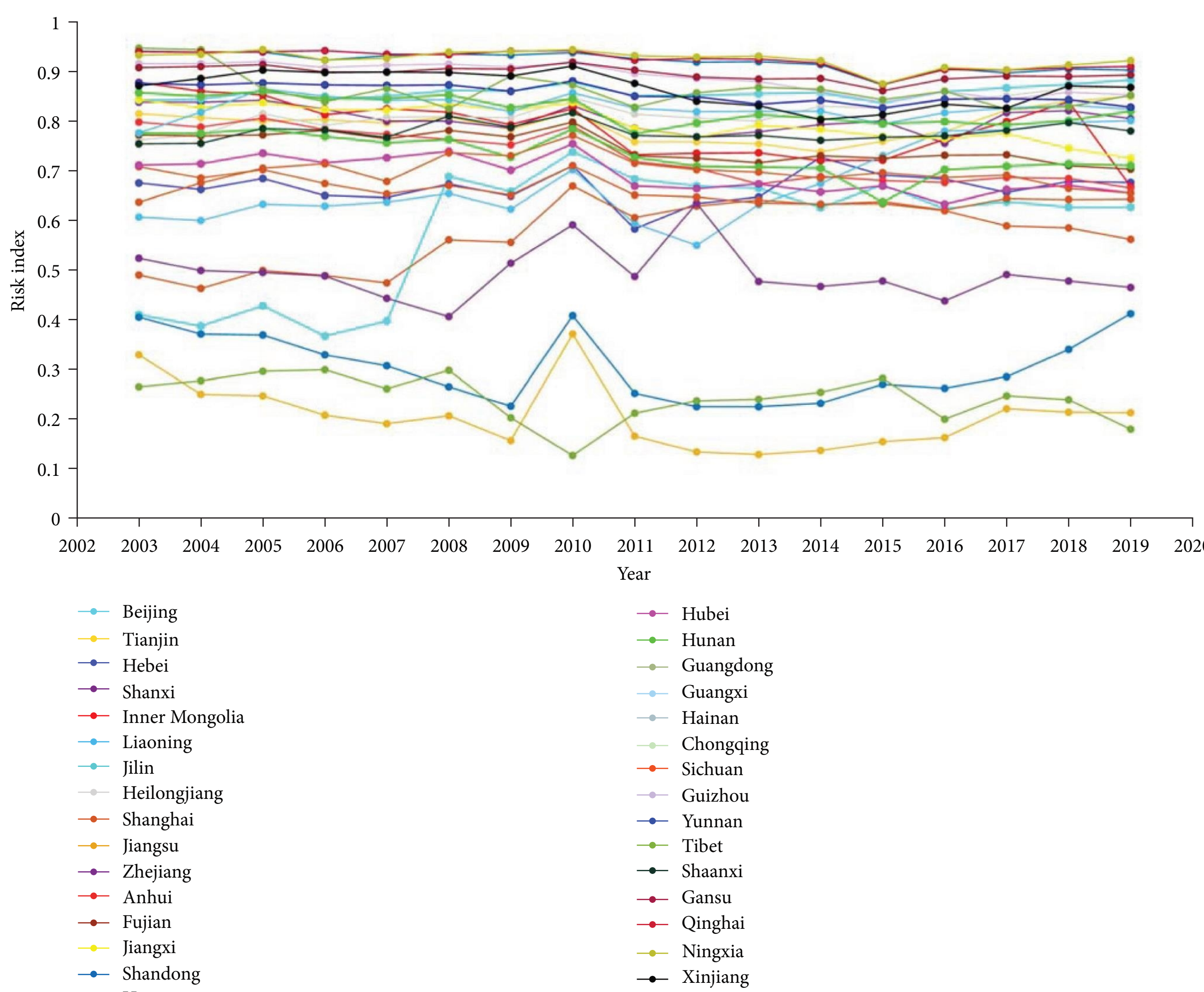

FIGURE 3: Line chart of PPP projects risk level in 31 provinces in China over the years from 2003 to 2019.

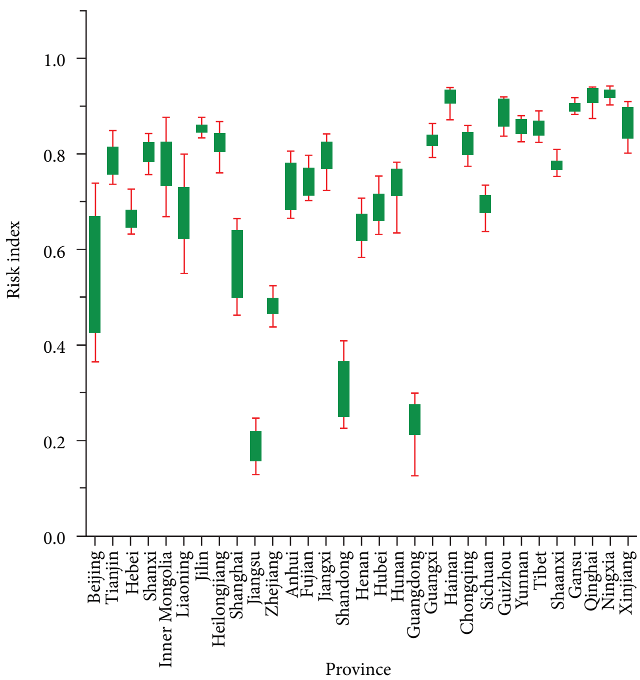

Figure 4: Box diagram of PPP projects risk level in 31 provinces in China.

of PPP projects was basically stable and in a stage of rapid development. In 2017, the Ministry of Finance issued the document "To Correct the Over Generalization and Abuse of PPP in Time" [63], demanding that the phenomenon of PPP irregularity be rectified vigorously, which led to a large number of PPP projects that failed to meet the standards all over the country being withdrawn from the project library. The risk of PPP was still at the medium-high level and increasing constantly, indicating that the overall risk level of PPP projects still had great adjustment potential and space.

In terms of regions (Figure 2), the risk value has always been western > central > national > eastern. Most of the western regions are economically underdeveloped, and their risk value is generally high. The risk index of PPP projects in western regions increased to 0.8811 by 2010, started to decrease after 2011, and dropped to 0.8371 in 2019. The risk index of PPP projects in central China was 0.7941 in 2003 and rise sharply to 0.8052 in 2010. Since then, it has been at a medium-high level. In 2003, the risk of PPP projects in the eastern region of China was at a medium level, rising to 0.6429 in 2010, declining in 2011, and then remaining at a medium level, with a slight fluctuation in 2017, rising to 0.6024 and fluctuating around 0.6 thereafter. Through comparative analysis, it can be seen that the risk level of PPP projects in the eastern region is relatively low compared with that in the central and western regions, and the rising speed is relatively fast. This is mainly based on the fact that the eastern region has the advantages of location and economy, strong scientific and technological innovation strength, and gradually tends to scale, intensive and low-carbon development. Therefore, the risk situation of PPP projects has improved significantly. However, owing to the constraints of natural factors, economic conditions, and historical reasons, as well as the imperfect development mechanism, the central and western regions starting late, the risk level of PPP projects in the western region is much higher than that in the eastern region.

In terms of provinces (Figure 4), over the past 17 years, there has been an overall upward trend in PPP projects in all provinces across the country, and the overall average annual growth rate of PPP projects in all provinces is 0.28%. The risk index of PPP projects in each province is significantly different, which is generally at a medium-high risk level. With the median as a reference, the risk index of each province ranks as follows: Ningxia (0.928) > Qinghai (0.925) > Hainan (0.922) > Gansu (0.898) > Guizhou (0.895) > Xinjiang (0.870) > Tibet (0.859) > Jilin (0.856) > Yunnan (0.856) > Guangxi (0.823) > Chongqing (0.819) > Heilongjiang (0.813) > Tianjin (0.799) = Shanxi (0.799) > Inner Mongolia (0.798) > Jiangxi (0.791) > Shaanxi (0.77) > Fujian (0.731) > Hunan (0.726) > Anhui (0.717) > Sichuan (0.695) > Hebei (0.672) = Hubei (0.672) > Henan (0.65) > Liaoning (0.636) > Beijing (0.626) > Shanghai (0.62) > Zhejiang (0.486) > Shandong (0.284) > Guangdong (0.246) > Jiangsu. Thus, the risk index of PPP projects in Ningxia, Qinghai, Hainan, Gansu, Guizhou, Xinjiang, Tibet, Jilin, Yunnan, and other regions is at a high level owing to the poor geographical environment and low public budget revenue, which leads to difficulty in financing PPP projects and a long landing period. In contrast, Zhejiang, Shandong, Guangdong, Jiangsu, and other regions have developed economies and abundant government financial funds, and the PPP projects risk index is less than 0.5, which is generally at the low-medium risk level.

4.2. Spatial Evolution Characteristics of PPP Project Risk Types. According to the temporal series evolution characteristics of PPP project risks in China, 2017 is selected as the representative time node in this research. Based on the risk level measurement and risk classification standard of PPP projects (Table 2), the corresponding spatial type distribution map of PPP project risks is drawn with ArcGIS10.2 software (Figure 5).

As can be seen in Figure 5, the risk status of PPP projects in China during the research period belongs to five levels, named: high risk, medium-high risk, medium risk, medium-low risk, and low risk.

In 2003, it can be seen from the chart that only Jiangsu, Shanghai, and Guangdong were at medium-low risk, and there were many provinces at medium and high risk, accounting for 80.64%. The western region is at a high-risk level, and the central region is at a medium-high risk level. Compared with 2003, Ningxia, Guangxi, and Heilongjiang in high-risk areas changed in 2008 to high-risk level. In 2010, the number of provinces in high-risk areas reached the maximum. The number of high-risk provinces in the central region increased, with only Guangdong at the low-risk level and Jiangsu at the middle-low-risk level. In 2014, according to data from the PPP Centre of the Ministry of Finance of China, with the increase of PPP projects, some provinces

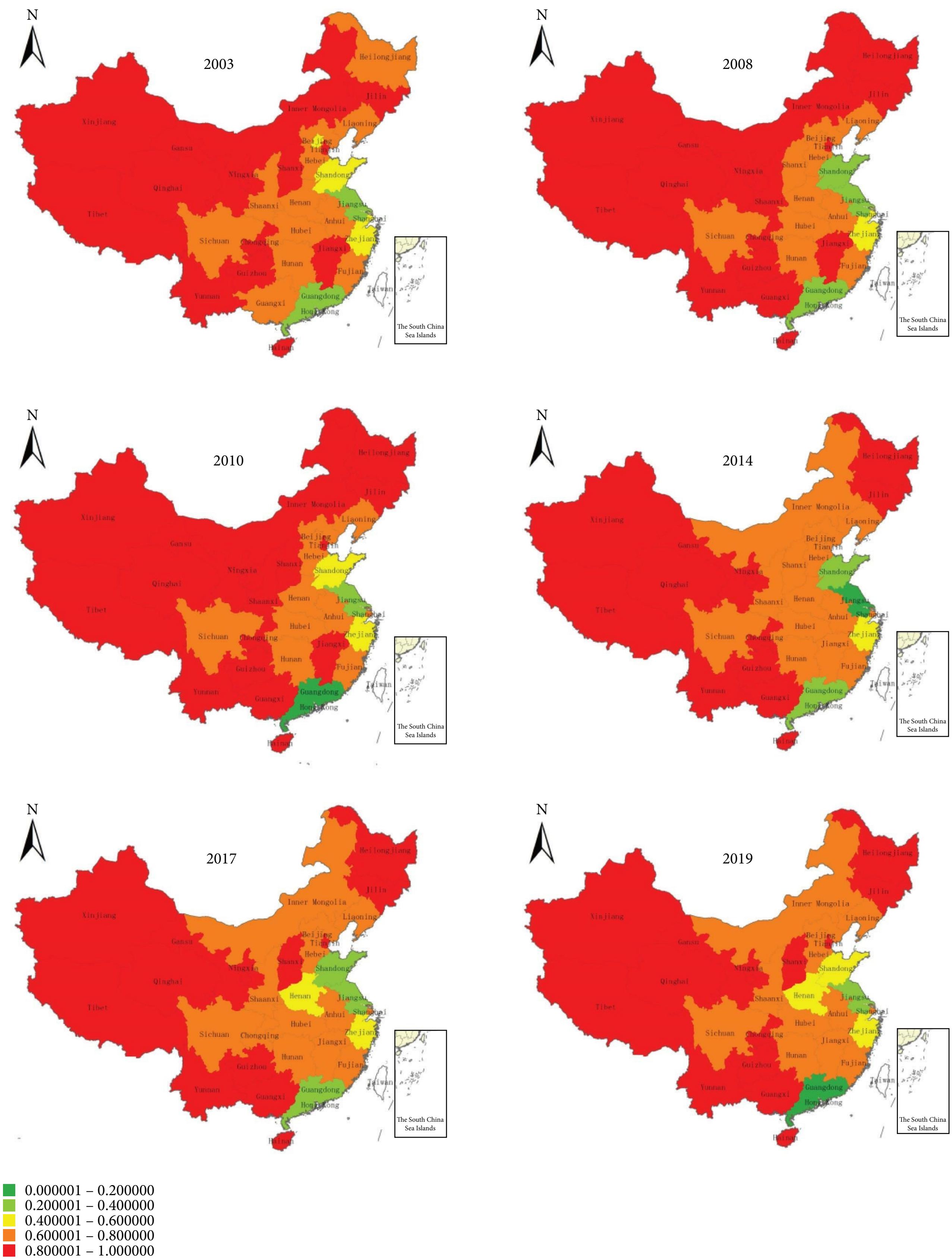

Figure 5: Distribution of risk types.

began to pay attention to the risk management of PPP projects [7], and some provinces in high-risk areas changed to low-medium risks, such as Inner Mongolia, Shaanxi, Shanxi, and Jiangxi provinces. In 2017, owing to the influence of the refunding policy, the risk level of PPP projects increased significantly in medium and high-risk areas, and Jiangxi reached high-risk levels. From 2017 to 2019, the risk level of PPP projects changed little, and Guangdong dropped to a low-risk level. From the change in spatial types of PPP project risks levels in China, the number of provinces with high-risk level and medium-high-risk level in the region gradually decreases, while the number of provinces with medium-risk level continues to increase. At present, the overall risk level of PPP projects is in the critical stage of transition from medium-high risk to medium risk. Overall, the risk of PPP projects is in the spatial pattern of higher in the west than in the east.

4.3. Spatial Variation Analysis of PPP Project Risks Pattern Evolution. A spatial variogram can well express the variation characteristics of the risk spatial structure of PPP projects. Taking the risk index of PPP projects from 2003 to 2019 as the spatial variable to give the geometric center of each regional unit, this paper uses Kriging interpolation to analyze the different characteristics and distribution patterns of the risk level of PPP projects in various provinces in China. *Sufer* software is used to visualize the interpolation results in three dimensions. Only the results for 2003, 2008, 2010, 2014, 2017, and 2019 are shown in Figure 6.

The Kriging interpolation simulation diagram of the PPP project risks level over seventeen years shows that the spatial–temporal pattern evolution of the risk level in China has certain continuity and regularity, and the spatial differentiation-level features are remarkable, showing the spatial evolution pattern of "western > central > eastern," while the high-value areas display an obvious westward migration phenomenon. Contour lines in the western and central regions are sparse, while those in the eastern region are dense, forming a "trough" centered on Guangdong, Shandong, Zhejiang, Jiangsu, and Shanghai.

From 2003 to 2008, PPP projects in China were in a stable promotion stage, and the government of the central region vigorously promoted the marketization of urban public utilities and encouraged domestic and foreign capital investment [9]. In this stage, under the active promotion of the state, PPP rose throughout China. Because the reform and opening-up were first implemented in the eastern region, to a certain extent, the eastern region was at the national leading level in terms of the economic environment, market system, and credit awareness.

Thus, the development of PPP in the eastern region was ahead of the central and western regions. Among them, the number of PPP projects in Fujian, Jiangsu, Zhejiang, Shandong, and Guangdong in China far exceeds that of other provinces, which indicates that the eastern region paid more attention to the PPP model. Based on these factors, the success rate of PPP projects was higher in the eastern region, and its risk index was relatively lower than that in the central and western regions. This laid the foundation for the overall risk index of PPP projects to show "western > central > eastern."

From 2009 to 2013, the Kriging interpolation simulation shows the trend that the risk index in the western region continued to rise; however, the central region decreased slightly, and the eastern region decreased. PPP projects were in a fluctuating stage. Because of the impact of the 2008 world financial crisis, the development of PPP in China was also been seriously affected [9]. To relieve the crisis, the Chinese government launched an investment plan of 4 trillion yuan (about 0.61 trillion USD) [62], with unrestricted investment by local governments. When implemented in the eastern region, most of the central region, and a small part of the western region, the risk index of various provinces in China has shown a trend of first increasing, then decreasing, and finally steadily developing.

Since 2014, PPP has been in a stage of rapid development, especially from 2014 to 2015; the landing of PPP projects received the greatest encouragement and support. However, the fluctuation of the overall risk index of all provinces in China has not been obvious during this stage. The results show that the number of PPP projects in the eastern region increased slightly, its risk index rose slightly, and its "trough" zone and characteristics are still obvious. The central and western regions were in the stage of rapid development and accelerated landing of PPP projects; their risk index declined slightly, and the contour line was gentle. From 2016 to 2018, to standardize the application of PPP mode and the implementation of PPP projects, the Ministry of Finance issued a series of policies to provide impetus for the steady development of PPP. At the end of 2017, the PPP projects in the project library that did not meet the specification requirements were cleaned up [7]. Based on this background, compared with Kriging interpolation simulation charts of each year at this stage, the risk index changed most obviously, and the overall risk index was the largest in 2018. The Kriging interpolation simulation diagram in 2019 shows that the risk index hardly fluctuated in the eastern and western regions and developed steadily. The risk index in the central region and the overall risk index in China showed a downward trend. To sum up, the standardization of China's PPP in the eastern region was becoming more and more obvious. By 2019, the development trend of PPP in the central region was moving closer to the eastern region. Drawing lessons from the development situation in the eastern and central regions, with the rural revitalization and the implementation of the new round of the National Western Development Plan, the western region of China will become the most promising region for the development of PPP in the future.

4.4. Spatial Correlation Analysis of PPP Project Risk. After using ArcGIS to visually express the PPP project risk value of each province, the spatial autocorrelation of PPP project risk data can be measured. It also analyzes whether there are clusters or outliers of PPP project risk in each province through global Moran's I and local Moran I's. Clarifying

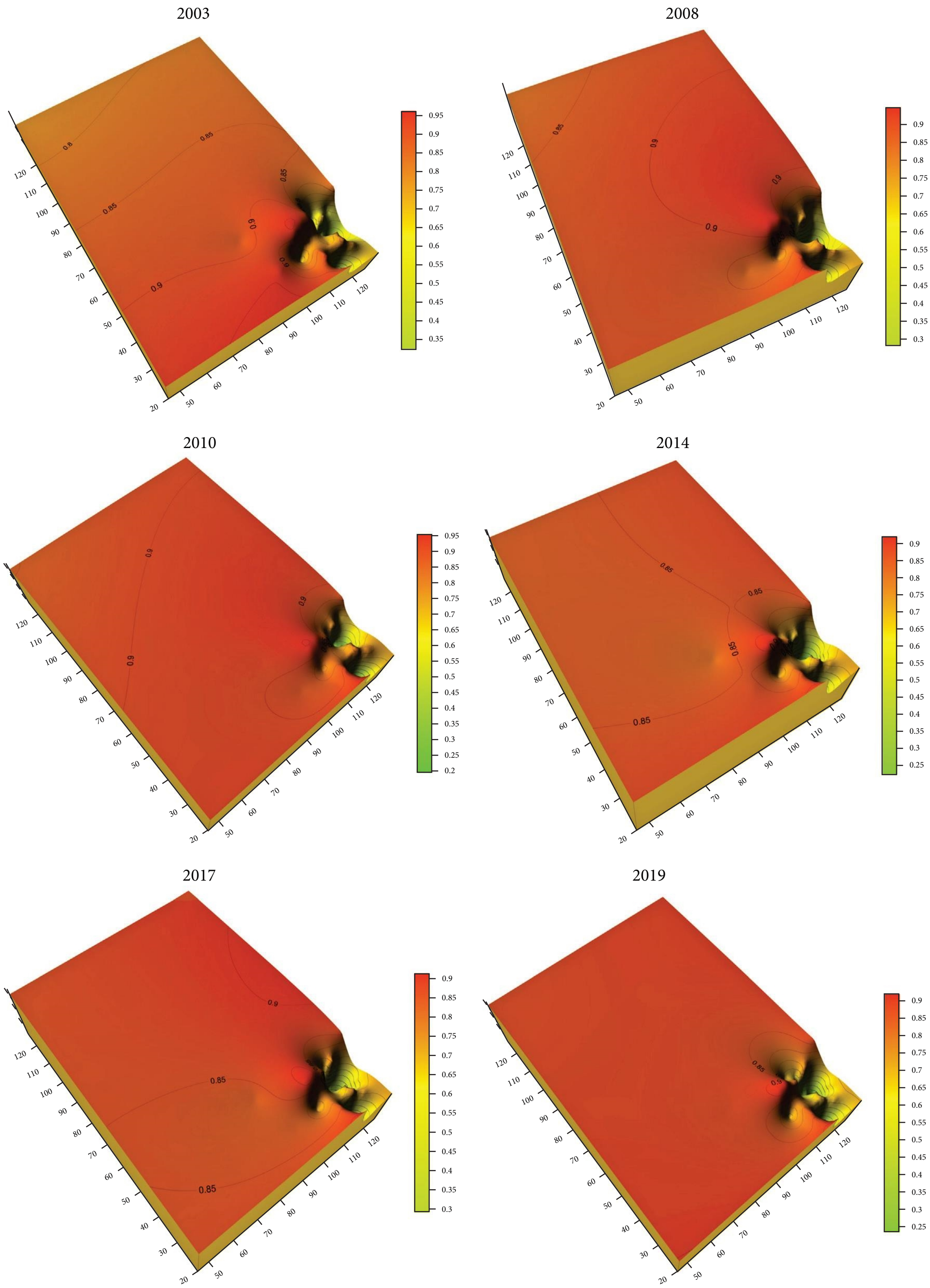

Figure 6: PPP project risks interpolation simulation in China in 2003, 2008, 2013, 2014, 2016, 2019.

Table 3: The global Moran's I in China from 2003 to 2019.

Year	I	E (I)	Sd (I)	Z	p-Value*
2003	0.147	−0.033	0.108	1.681	0.046
2004	0.203	−0.033	0.107	2.202	0.014
2005	0.212	−0.033	0.107	2.291	0.011
2006	0.225	−0.033	0.107	2.415	0.008
2007	0.230	−0.033	0.107	2.459	0.007
2008	0.267	−0.033	0.105	2.856	0.002
2009	0.240	−0.033	0.104	2.622	0.004
2010	0.131	−0.033	0.100	1.648	0.050
2011	0.236	−0.033	0.105	2.570	0.005
2012	0.216	−0.033	0.103	2.411	0.008
2013	0.251	−0.033	0.104	2.742	0.003
2014	0.222	−0.033	0.104	2.464	0.007
2015	0.255	−0.033	0.103	2.794	0.003
2016	0.251	−0.033	0.104	2.730	0.003
2017	0.260	−0.033	0.105	2.802	0.003
2018	0.280	−0.033	0.105	2.992	0.001
2019	0.204	−0.033	0.105	2.268	0.012

Table 4: Judgment basis of Moran's I remarkable situation.

Z (standard deviation)	p-Value	Confidence level (%)
<-1.65 or $>+1.65$	<0.10	90
<-1.95 or $>+1.95$	<0.05	95
<-2.58 or $>+2.58$	<0.01	99

the location of outliers or clusters is more conducive to accurately grasping the spatial information and controlling the PPP project risk.

4.4.1. Moran's I Analysis. Global spatial autocorrelation analysis is usually used to reflect the overall spatial differences and spatial associations of different regions. This paper utilizes the spatial econometric software *Stata* to calculate the global Moran's I and test the spatial correlation and spatial dependence of PPP project investment in 31 provinces in China. The global Moran's I is shown in Table 3 Judging by Table 4.

According to the judgment (Table 4), the Z-values from 2003 to 2019 are all significant, which shows that the PPP projects risk levels of 31 provinces in China have spatial autocorrelation in regional distribution, resulting in an aggregation effect.

4.4.2. Scatter Chart and Agglomeration Chart Analysis. In order to further measure the local spatial correlation, the degree of spatial difference, and the distribution of spatial patterns between each region and its neighbors, we conducted a spatial statistical analysis of China's PPP project risk values by scatter plots and LISA aggregation maps.

(1) Scatter Chart Analysis. Scatter charts can directly reflect the types and spatial distribution of the spatial correlation of risk levels in various provinces. Using *Stata* software, we can output the scatter charts of PPP projects risk levels in various provinces in China in each year in Figure 7 (owing to space limitations, only take 2003, 2008, 2010, 2013, 2017, and 2019 as examples) and summarize the evolution paths of PPP projects risk levels in various provinces, as shown in Table 5.

Figure 8 shows the scatter charts of Moran's I of each year in China, and it is divided into four quadrants, which respectively reflect the spatial distribution characteristics of PPP project risk values in different regions of China. From the perspective of local correlation, the points in the first and third quadrants are obviously more than those in the second and fourth quadrants. Besides, the regions with higher and lower risk levels are more likely to cluster in space, which verifies the status of bipolar clustering of PPP project risks in China.

From the perspective of each province, the PPP project risk level of most provinces was in a relatively stable state from 2003 to 2019. The PPP project risk level of Hebei experienced LL, LH, and HL clustering in sequence during the observation period, which was the result of continuous competition with surrounding areas. The GDP, public finance revenue, and technical capital investment in Hebei were stagnant compared with surrounding provinces after 2017. Hunan and Inner Mongolia provinces have crossed from HH to LH quadrant, but surrounding provinces are still in a high-risk state. In 2010, the risk level of PPP projects between Guangxi and its surrounding areas was relatively backward from the previous year, and it crossed from HH to HL quadrant after 2010, which was closely related to its neighboring Hunan province's crossing from HH to LH. Anhui and Fujian were in the HL quadrant from 2003 to 2010. By strengthening economic construction and reducing the degree of spatial differences with surrounding areas, they have all entered the LL quadrant.

From the perspective of three major regions, Shanghai, Jiangsu, Zhejiang, and Shandong provinces in the eastern region have the same development trend as Henan and Anhui provinces in the central region. The phenomenon not only indicates that China's PPP project risk level has a certain synergistic mechanism but also reduces the PPP project risk level in the eastern and central regions as a whole. The PPP project risk level of Beijing and Guangdong is lower than that of surrounding areas, while that of Tianjin, Hainan, and Guangxi is the opposite. In the central region, except Anhui and Henan, which enter the LL quadrant, other provinces are distributed in the other three quadrants, which leads to a high PPP project risk level in the central region. In the western region, except for Sichuan's PPP project risk level is in the LH quadrant, and other provinces are in the HH quadrant.

The aforementioned two levels reflect that there is always spatial autocorrelation and spatial heterogeneity in China's PPP projects risk level, which has formed a relatively stable spatial pattern; that is, the risk level increases from east to west.

(2) LISA Aggregation Chart Analysis. The scatter chart cannot judge whether the local correlation types and their

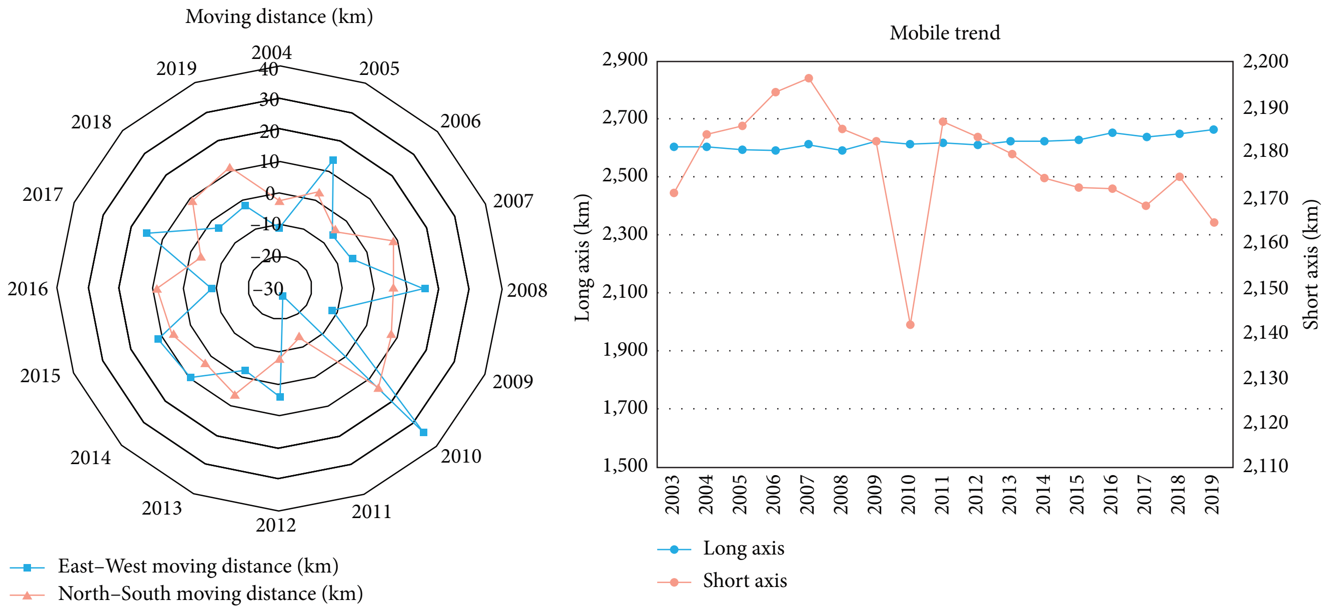

Figure 7: Shift distance and major and minor axis changes of the center of gravity of PPP project risks in China from 2003 to 2019.

Table 5: Evolution path of PPP projects risk level in China.

Year	HH quadrant	LH quadrant	LL quadrant	HL quadrant
2003	Heilongjiang, Jilin, Xinjiang, Inner Mongolia, Tibet, Qinghai, Ningxia, Gansu, Shaanxi, Shanxi, Hunan, Guangxi, Chongqing, Guizhou, and Yunnan	Liaoning, Beijing, Hubei, Sichuan, and Guangdong	Jiangsu, Shandong, Zhejiang, Shanghai, Henan, and Hebei	Hainan, Tianjin, Fujian, Jiangxi, and Anhui
2008	Heilongjiang, Jilin, Xinjiang, Inner Mongolia, Tibet, Qinghai, Ningxia, Gansu, Shaanxi, Shanxi, Hunan, Guangxi, Chongqing, Guizhou, Yunnan, and Sichuan	Liaoning, Beijing, Hubei, and Guangdong	Jiangsu, Shandong, Zhejiang, Shanghai, Henan, and Hebei	Hainan, Tianjin, Fujian, Jiangxi, and Anhui
2010	Heilongjiang, Jilin, Xinjiang, Inner Mongolia, Tibet, Qinghai, Ningxia, Gansu, Shaanxi, Shanxi, Chongqing, Guizhou, Yunnan, and Sichuan	Liaoning, Beijing, Hubei, and Guangdong	Jiangsu, Shandong, Zhejiang, Shanghai, Henan, and Hebei	Hainan, Tianjin, Fujian, Jiangxi, Anhui, Hunan, and Guangxi
2014	Heilongjiang, Jilin, Xinjiang, Inner Mongolia, Tibet, Qinghai, Ningxia, Gansu, Tianjin, Shaanxi, Shanxi, Chongqing, Guizhou, and Yunnan	Liaoning, Beijing, Hubei, Hunan, Sichuan, and Guangdong	Jiangsu, Shandong, Zhejiang, Shanghai, Henan, and Anhui	Hainan, Fujian, Jiangxi, Guangxi, and Hebei
2017	Heilongjiang, Jilin, Liaoning, Xinjiang, Inner Mongolia, Tibet, Qinghai, Ningxia, Gansu, Shaanxi, Shanxi, Chongqing, Guizhou, and Yunnan	Hunan, Beijing, Hubei, Sichuan, and Guangdong	Jiangsu, Shandong, Zhejiang, Shanghai, Henan, Hebei, and Anhui	Hainan, Tianjin, Fujian, Jiangxi, and Guangxi
2019	Heilongjiang, Jilin, Xinjiang, Tibet, Qinghai, Ningxia, Gansu, Shanxi, Chongqing, Guizhou, and Yunnan	Liaoning, Inner Mongolia, Beijing, Hebei, Hubei, Hunan, Sichuan, and Guangdong	Jiangsu, Shandong, Zhejiang, Shanghai, Anhui, Fujian, and Henan	Hainan, Tianjin, Guangxi, and Jiangxi

Note. The first quadrant is high–high (HH), which means the area with high PPP project risk value is surrounded by other areas with high PPP project risk value. The second quadrant is low–high (LH), which means: the area with low PPP project risks value is surrounded by other areas with high PPP project risks. The third quadrant is low–low (LL), which means the area with low PPP project risk value is surrounded by other areas with low PPP project risks. The fourth quadrant is high-low (HL), which means the area with high PPP project risk value is surrounded by other areas with low PPP project risks. The phenomenon means that there are more provinces with "high–high" and "low–low" clusters than those with "high–low" and "low–high" clusters.

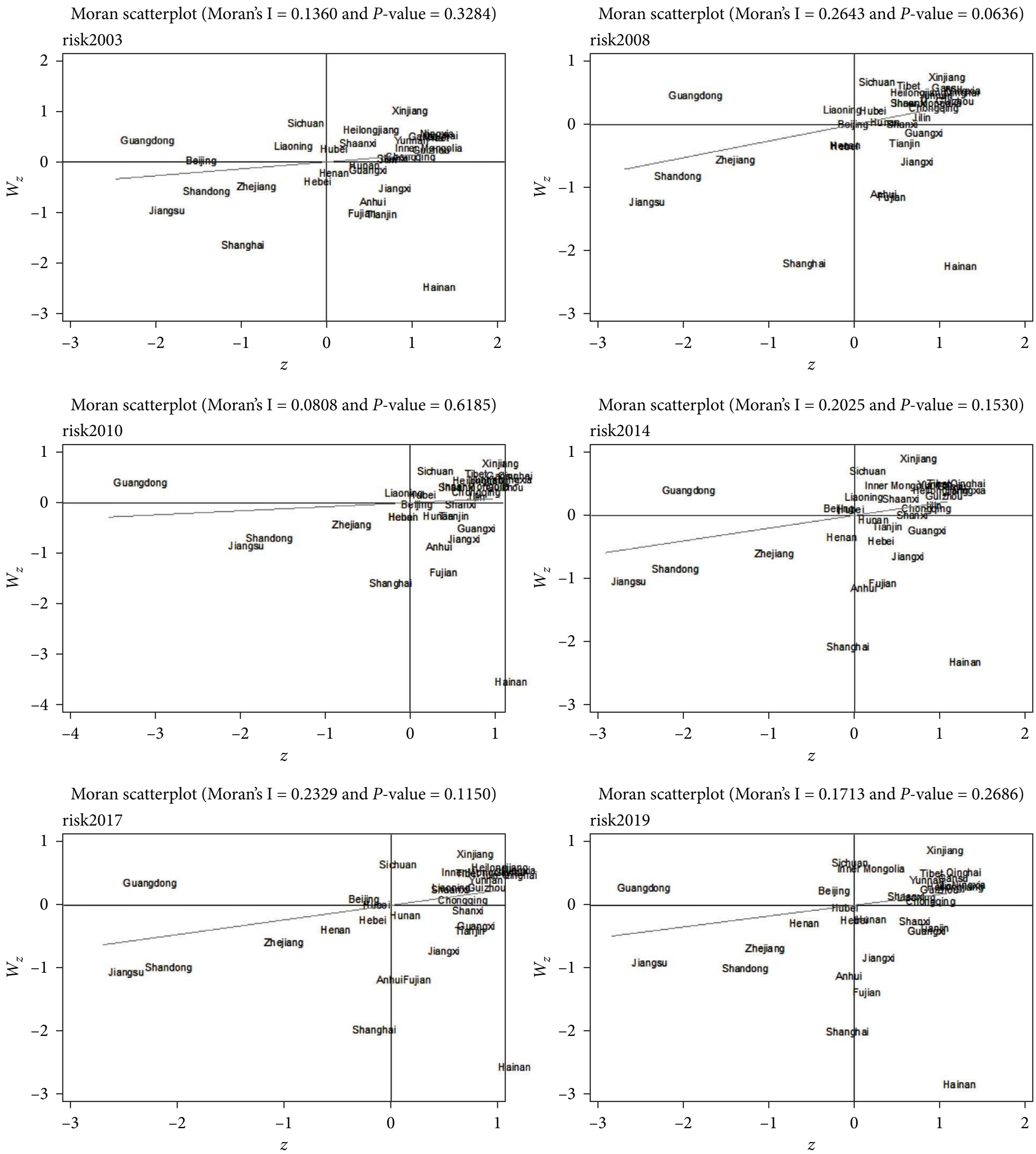

Figure 8: Scatter charts of Moran's I in China's provinces and cities.

clustering areas in each region are statistically significant. The following is the LISA clustering chart (as shown in Figure 9) of China's PPP projects risk level (owing to space limitations, only taking 2003, 2008, 2010, 2013, 2017, and 2019 as examples) using *Geoda* software, and the clustering results of risk levels in various provinces are summarized, as shown in Table 6.

From the perspective of the agglomeration effect (Figure 10), Anhui shows an obvious leapfrogging phenomenon in 2014 (from HL quadrant to LL quadrant), Inner Mongolia shows an obvious leapfrogging phenomenon in 2019 (from HH quadrant to LH quadrant), and Fujian shows an obvious leapfrogging phenomenon in 2019 (from HL quadrant to LL quadrant). Besides, most of the provinces included in the four quadrants are relatively stable. Among them, the LL quadrant has the largest number of provinces, most of which are the eastern provinces. HH quadrants are all western provinces. LH quadrant is mainly composed of Sichuan. The HL quadrant mainly includes

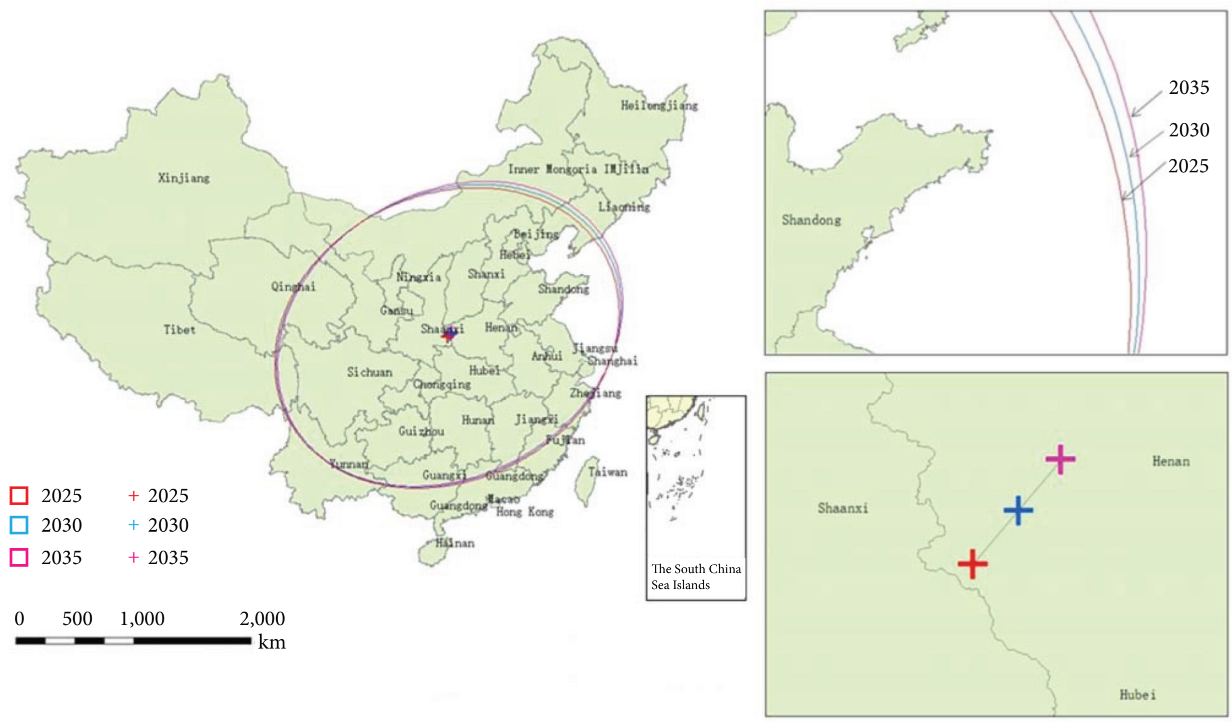

Figure 9: Spatial prediction pattern in 2025, 2030, 2035.

Table 6: LISA aggregation results.

Year	HH quadrant	LH quadrant	LL quadrant	HL quadrant
2003	Xinjiang	Sichuan	Jiangsu and Shanghai	Anhui and Hainan
2008	Xinjiang and Gansu	Sichuan	Shandong, Jiangsu, and Shanghai	Anhui and Fujian
2010	Xinjiang, Gansu, and Sichuan		Jiangsu and Shanghai	Anhui, Jiangxi, Fujian, and Hainan
2014	Xinjiang	Sichuan	Shandong, Anhui, Jiangsu, and Shanghai	
2017	Xinjiang, Gansu, and Inner Mongolia	Sichuan	Shandong, Anhui, Jiangsu, and Shanghai	Jiangxi, Fujian, and Hainan
2019	Xinjiang	Sichuan and Inner Mongolia	Shandong, Anhui, Jiangsu, Shanghai, and Fujian	Jiangxi and Hainan

Hainan and Jiangxi, which shows that the risk level of China's PPP projects between these provinces and their surrounding areas has always been quite different.

From the perspective of coordinated development, the number of provinces in the LL quadrant is increasing. The six provinces of Shandong, Anhui, Jiangsu, Shanghai, Zhejiang, and Fujian are adjacent to each other, and the synergistic effect of the regional PPP project risk level is obvious. From a holistic perspective, the number of provinces in HH quadrant is decreasing, but the risk level in Xinjiang is obviously high. These two phenomena suggest that the spatial polarization of the PPP project risk level in China is becoming more and more obvious.

4.5. Elliptic Analysis and Trend Prediction of PPP Project Risks Standard Deviation. Based on the previous analysis of the evolution of spatial variability of PPP project risks in China, it can be seen that this variability is characterized by significant. Therefore, in order to reveal the spatial pattern characteristics of China's PPP project risks from multiple angles, explore its future evolution regularity, and take targeted measures, this paper further analyses its spatial distribution direction characteristics and development trend based on standard deviation elliptic model and gray GM (1,1) model.

4.5.1. Elliptic Analysis of Risk Standard Deviation of PPP Projects. The ArcGIS Desktop spatial statistics module is utilized to obtain the main parameters of the standard deviation ellipse of China's PPP project risks. On this basis, the moving path, moving distance (east–west direction and north–south direction), and moving trend of the center of gravity of the standard deviation ellipse are described. Furthermore, the spatial distribution pattern of PPP project risks in China is obtained, as shown in Figures 7 and 11.

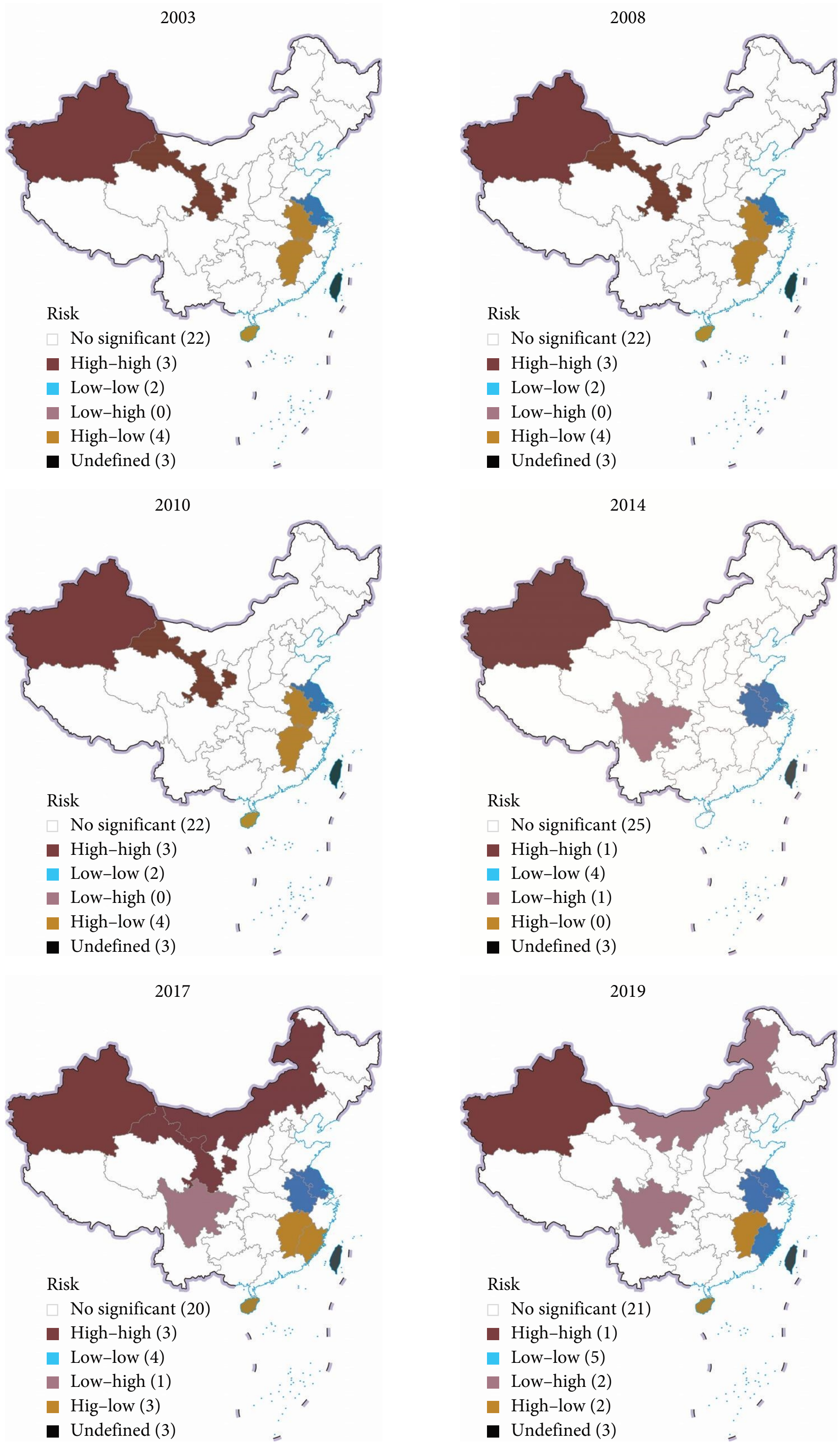

Figure 10: LISA aggregation chart of PPP projects risk level in China.

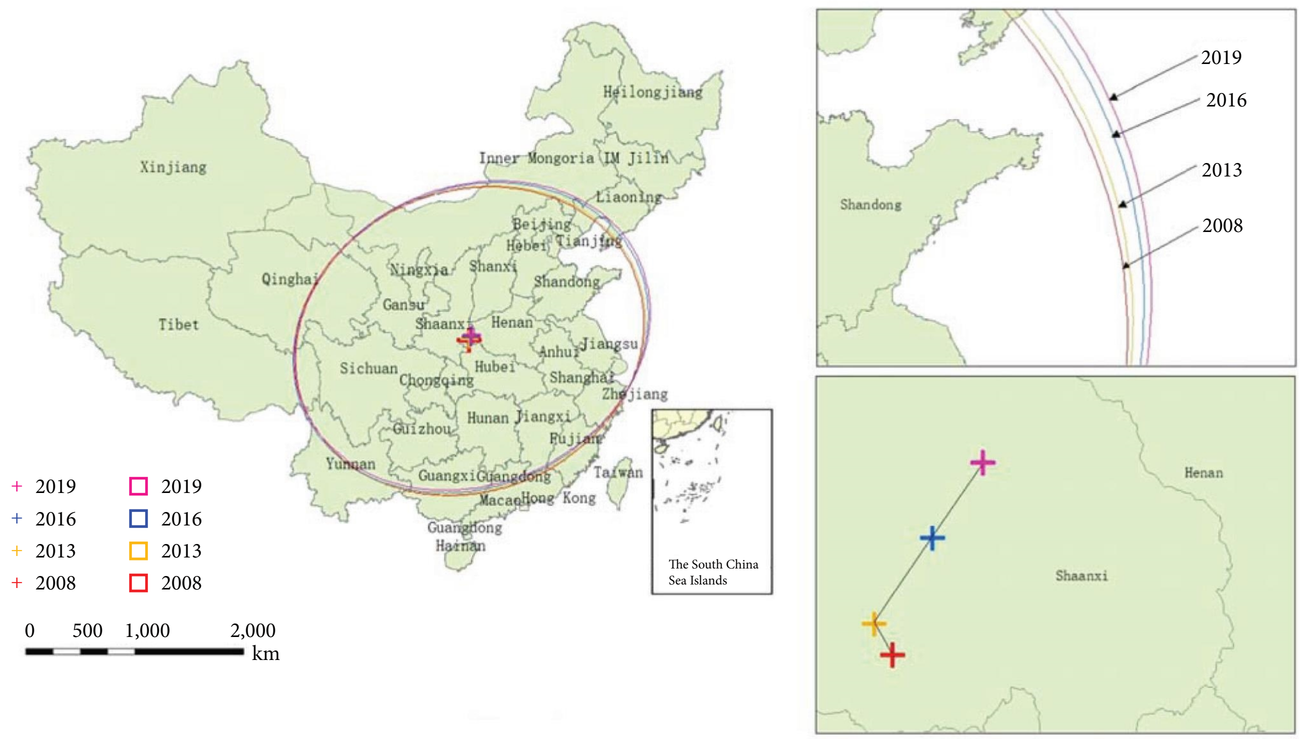

Figure 11: Elliptic distribution of standard deviation and moving path of the center of gravity of PPP project risks in China.

From 2003 to 2019, the dynamic evolution characteristics of the risk space of PPP projects in China were significant, and the overall movement trend shifted from northwest to northeast (Figure 11). Taking 2013 as the turning point, the shift path of the center of gravity of PPP project risks can be divided into two stages: from 2008 to 2013, it moved to the northwest, and from 2013 to 2019, it moved to the southeast. In terms of moving distance, the standard deviation ellipse's moving is that the east is greater than the west, the north is greater than the south, and the east–west is greater than the north–south. Among them, the total distance moved in the east–west is twice that of the distance moved in the north–south. The total displacement was 55.804 km, of which 24.884 km moved eastward and 49.949 km moved southward (Figure 7). The reason for the shift in the center of gravity lies in the following: at the initial stage of the study period, owing to the influence of economic conditions, PPP projects first appeared and developed rapidly in the eastern region, and with the development of the northwest region, PPP project risks shifted to the northwest region. With the slowdown of GDP growth, the increase in fiscal revenues in the eastern region has also slowed down, the pressure of fiscal revenue and expenditure increases, and the ability to support economic and social development weakens. In particular, the expenditure on basic public services such as education, social security, employment, and healthcare shows a rigid growth trend. It is necessary to increase fiscal expenditure to deal with ecological environment restoration and management, population aging, urbanization, and improving weak links. The contradiction between revenue and expenditure has become acute in some local governments, especially at the county level, where the financial pressure is extremely high and the financial operation risk has risen. The relative insufficiency of social security capacity in some northeastern provinces has increased the pressure of fiscal sustainability, and the focus of PPP project risk has shifted to the northeast.

From the elliptic distribution shape of standard deviation (Figure 7), the short axis has a small floating amplitude, the long axis has a fluctuating trend, and its distribution pattern has an obvious southeast–southwest–southeast trend. In particular, the distribution range of the standard deviation ellipse expanded from 2003 to 2007. At this stage, the area of the standard deviation ellipse increased from 44.4066×105 to $45.063 \times 105\,\text{km}^2$, and the long and short axes increased from 2,604.929 and 2,170.559 km in 2003 to 2,612.585 and 2,196.122 km in 2007, respectively. From 2007 to 2010, the ellipse distribution range of standard deviation showed a shrinking trend. With the ellipse area of standard deviation dropping to $43.969 \times 105\,\text{km}^2$, the long axis and short axis dropping to 2,614.468 and 2,141.265 km in 2010, which indicated that the risks of PPP project were concentrated in the north–south and east–west directions, and the spatial spillover effect was reduced. In 2011, the ellipse distribution range increased briefly. From 2012 to 2019, the standard deviation ellipse area fluctuated from $44.803 \times 105\,\text{km}^2$ to $45.276 \times 105\,\text{km}^2$, the long axis fluctuated from 2,612.931 to 2,663.778 km, and the short axis fluctuated from 2,183.174 to 2,164.120 km. It shows that the spatial distribution pattern of PPP project risks in China was relatively stable at this stage. Although the east–west direction is the principal direction of the spatial distribution of PPP project risks, the north–south direction is also becoming more balanced.

4.5.2. Prediction of Risk Spatial Pattern of PPP Projects. By using *SPSSAU* software, based on the gray GM (1, 1) model, the time series model of five parameters of the standard deviation ellipse of the risk of China's PPP projects was constructed, and the prediction results were examined by the residual test and the post hoc difference test. Among the research results, the average relative errors of the five parameters are all less than 7%, and the accuracy grades of variance ratio and small error probability are both Grade I and Grade II. It indicates that the prediction results of GM (1, 1) model are highly reliable. On this basis, by applying Arcgis10.2 software, the predicted ellipse parameters of standard deviation in 2025, 2030, and 2035 are visually expressed, and the spatial distribution pattern is outlined, as shown in Figure 11.

In terms of changes in the spatial distribution range, the area of the standard deviation ellipse will increase from $45.276 \times 105\,\text{km}^2$ in 2019 to $45.79 \times 105\,\text{km}^2$ in 2035, and the long and short axis will increase from 2,663.778 and 2,164.120 km in 2019 to 2,718.368 and 2,144.718 km in 2035, respectively, and indicating that in the future, the spatial distribution pattern of PPP project risks in China will spread in east–west and north–south directions, and the spatial spillover effect is obvious. Therefore, it can be predicted that in the future, the risk problems of PPP projects will still be mainly manifested in the economically underdeveloped western and central provinces. The balanced development of risk space of PPP projects will remain an important challenge for the sustainable development of PPP projects in China in the future.

5. Discussion and Conclusion

5.1. Major Findings. This paper constructs the PPP project risks evaluation index system based on the DPSIR model, and it uses the entropy value TOPSIS method, spatial variation model, standard deviation ellipse model, gray dynamic model, Moran's I, etc., to discuss in depth the temporal and spatial evolution characteristics and development trend of China's PPP project risks from 2003 to 2019. The results show the following:

(1) During the research period, the average risk level of China's PPP projects was 0.722, and the comprehensive risk index dropped from 0.735 to 0.716; the risk situation is downward trending and stable, indicating that the overall risk status of PPP projects is developing in a positive direction, but there is still great potential and space for improvement. Among the three regions, the risk index of PPP projects in the western region is higher, followed by the central region, and the risk index in the eastern region is the lowest.

(2) Over the past 17 years, the risk status of PPP projects in China has been categorized into five levels. Among them, the number of provinces and municipalities at the high-risk level and medium-high-risk level has gradually decreased, while the number of provinces and municipalities at the medium-risk level has continued to increase. At present, the overall risk level of PPP projects is at a critical stage of transition from medium to low.

(3) The degree of spatial variation of PPP project risks is constantly increasing, and the structural differentiation caused by spatial autocorrelation is gradually weakening, while the spatial difference caused by random components is more and more significant. The level of spatial differentiation is characterized by obvious features, generally showing the spatial evolution pattern of "west > central > east," and the low-value area shows obvious southeastern migration phenomenon.

(4) The spatial distribution pattern of PPP project risks is northeastward, the moving path is "northwest → northeast," and the spatial distribution range has experienced the process of "dispersion—aggregation—dispersion." The prediction results show that in 2020–2035, the risk center of China's PPP project will move to the northeast, the distribution pattern will be dispersed in the east–west–south–north direction, and the spatial spillover effect is not obvious.

The PPP project risks in China's provinces and cities have obvious geographical dispersion. The economic situation in the eastern region is optimistic, the motivation to implement PPP mode is insufficient, and the risk performance is minimal. The northeast and midwest regions, which are lagging behind in economic development, are keen on the PPP model and show a higher level of risk, so participants need to strengthen project risk identification and control. Reasons may include: (1) The PPP model is more conducive to implementation in the midwestern environment, which can quickly improve and upgrade the infrastructure construction. The most obvious feature of PPP is that it is government-led and strongly promoted from top to bottom. In the document issued by the Ministry of Finance, high expectations are placed on the use of PPP mode to accelerate the transformation of government functions, enhance national governance capacity, deepen the reform of the fiscal and taxation system, and build a modern financial system. However, in actual implementation, the central and western regions with poor economic and financial situations are difficult to change well, and the balance of economic base and social development is insufficient. (2) Influence of macroeconomic environment on PPP project. China's economy is in the stage of comprehensive transformation, and it is characterized by the economic downturn, declining growth, weak imports and exports, and the impact of the COVID-19 epidemic. The export-oriented economic environment in the central and western regions are more vulnerable to impact, and new economic growth points are urgently needed to promote economic development. The government consciously attracts social capital through PPP mode in the field of infrastructure, thus driving the capital market, stimulating investment, and promoting consumption.

5.2. Conclusion. The spatial and temporal evolution of PPP project risk characterization is a new area of PPP research.

First, this paper calculated the comprehensive risk index of PPP projects in various provinces and cities in China from 2003 to 2019. In the temporal dimension, the composite index of PPP project risks shows an upward trend from 2003 and starts to decline after reaching the highest level in 2010. This may be related to the fact that China's PPP program was in a developmental phase from 2003 to 2008 and a fluctuating phase from 2009 to 2012 [7, 64]. This research shows that the risk value of PPP projects has a downward trend in fluctuations from 2010 to 2019, which may be caused by the increasing standardization of PPP projects. This is consistent with the existing research, such as Cheng et al.'s studies [7], which concluded that after 30 years of development, the operation of PPP projects in China has become more standardized and transparent. In terms of spatial, the risk of PPP projects is lower in the eastern region and higher in the western region. This is related to the high degree of marketization and a good level of economic development in the eastern region, while in the underdeveloped western region, the government's financial funds are tight, which cannot provide a good development environment for PPP projects.

Second, there are differences between the research subjects of this study and previous studies. This paper takes the risk value of PPP projects in China as the starting point to explore the agglomeration and difference of its spatial distribution, filling the gap in the research of spatial differentiation in the field of PPP project risks. This is different from the existing research, such as Cheng et al.'s [7] and Wang et al.'s studies [65], which analyzed the spatial correlation and difference of PPP from the investment and financing amount or scale of the project.

Third, the research methods in this paper are different from those in the past. This paper evaluates the risks of PPP projects in different years in China through large sample data and forecasts the evolution trend of PPP projects in China based on the measured results. The research results can roughly judge the risk level of PPP projects in China in the future and enrich the related research of risk management. This is different from the existing research, such as Feng et al.'s [66], Liu et al.'s [67], and Zhang et al.'s studies [68], which quoted a single case, structural equation model, or neural network to evaluate PPP risks.

5.3. Managerial Implications. Based on the analysis of the temporal and spatial evolution characteristics of PPP project risks in China, the following suggestions are put forward: the state, provinces, and cities should formulate comprehensive and reasonable rules and regulations to ensure and standardize the implementation of PPP projects. The eastern region should continue to capitalize on its regional capital and talent advantages, strive to raise the level of scientific and technological innovation, and intensify industrial upgrading to create an innovative and entrepreneurial economy with high growth and high returns. At the same time, the ecological environment accounts for 16.47% of the weight, which indicates that ecological environmental protection is an important research direction in the future. In order to comprehensively improve the risk situation of PPP projects, we should break the territoriality, establish the concept of ecological community, and realize the effective communication of the risk information of inter-regional PPP projects, so as to reduce the constraints and influences of spatial effects on the risks of PPP projects.

5.4. Limitations and Future Directions. This study enriches the research results in this field to a certain extent, but it also has certain limitations. First, this study focuses on the spatial and temporal evolution characteristics of PPP project risks in Chinese provinces. However, the intricate interactions between various factors affecting PPP project risks may not be fully reflected in the scope of this study. Second, future research could try to start from the microlevel in terms of the scope of the study by refining the PPP project risk data to the city scale, which may make the study more scientific and accurate. Therefore, in the future research, we can consider more interactions between PPP project risk influencing factors and explore more combinations of external influencing factors and internal constraints. Second, as the risk formation mechanism of PPP projects is a dynamic process, we can study the factors that lead to the formation of risk from the natural, social man-made factors, so as to discover the sources of risk in time and manage and control them. In addition, by combining remote sensing data, machine learning technology and advanced spatial analysis methods, we can understand the spatial pattern and driving factors behind the risks of PPP projects in more detail.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Authors' Contributions

Conceptualization was done by Y.H. and Y.W; methodology was done by Y.H. and Y.W; validation was done by X.H. and S.Z; data were done by H.X; investigation was done by L.G. and J.Z; software-related task was done by L.G. and S.Z; formal analysis was done by Y.H. and Y.W; resources were provided by Y.H. and Y.W; writing—original draft was done by L.G. and Y.W; writing—review and editing was done by Y.H. and Y. W. All authors have read and agreed to the published version of the manuscript.

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References

[1] China Public Private Partnership Centre, "National PPP integrated information platform project management database," 2021, http://www.cpppc.org:8086/pppcentral/map/toPPPMap.do.

[2] China Public Private Partnership Centre, "National PPP integrated information platform project management database," 2022, http://www.cpppc.org:8086/pppcentral/map/toPPPMap.do.

[3] China Public Private Partnership Centre, "National PPP integrated information platform project management database," 2018, http://www.cpppc.org:8086/pppcentral/map/toPPPMap.do.

[4] J. Cai, J. Lin, Z. Yang, X. Zhou, and Z. Cheng, "Retro or renewal: an assessment of PPP management and policy in China since 2014," *Public Works Management & Policy*, vol. 26, no. 4, pp. 359–380, 2020.

[5] PPP Centre of Ministry of Finance, "National PPP integrated information platform project management 5Library 2018 annual report," 2018.

[6] B. Wei, X. Guo, and Z. Wang, "PPP mode and regional economic development—empirical evidence from coastal areas of China," *Journal of Coastal Research*, vol. 112, no. sp1, pp. 262–268, 2020.

[7] Z. Cheng, Y. Ke, J. Lin, Z. Yang, and J. Cai, "Spatial–temporal dynamics of public private partnership projects in China," *International Journal of Project Management*, vol. 34, no. 7, pp. 1242–1251, 2016.

[8] Y. Guo, I. Martek, and C. Chen, "Policy evolution in the Chinese PPP market: the shifting strategies of governmental support measures," *Sustainability*, vol. 11, no. 18, Article ID 4872, 2019.

[9] Development Process and Characteristics of PPP of China, 2017, China, 1984-2017 http://www.bridata.com/.

[10] X. An, H. Li, L. Wang, Z. Wang, J. Ding, and Y. Cao, "Compensation mechanism for urban water environment treatment PPP project in China," *Journal of Cleaner Production*, vol. 201, pp. 246–253, 2018.

[11] L. Zhang, X. Sun, and H. Xue, "Identifying critical risks in Sponge city PPP projects using DEMATEL method: a case study of China," *Journal of Cleaner Production*, vol. 226, pp. 949–958, 2019.

[12] H. Zhang, L. Yu, and W. Zhang, "Dynamic performance incentive model with supervision mechanism for PPP projects," *Engineering, Construction and Architectural Management*, vol. 27, no. 9, pp. 2643–2659, 2020.

[13] Y. Wang, W. Song, B. Zhang, and R. L. K. Tiong, "Official tenure, fiscal capacity, and PPP withdrawal of local governments: evidence from China's PPP project platform," *Sustainability*, vol. 13, no. 24, Article ID 14012, 2021.

[14] L. She and J. Li, "The research status and prospects of public–private partnership in China," in *ICCREM 2017*, pp. 256–261, ASCE, 2017.

[15] L. A. Tolstolesova, N. N. Yumanova, and E. V. Mazikova, "Realization of PPP projects in the sector of energetics as a condition of a sustainable development of macroregions," *Entrepreneurship and Sustainability Issues*, vol. 49, no. 9, pp. 263–277, 2019.

[16] M. Rashed, M. Alam, and M. Toriman, "Considerable issues for sustainable public–private partnership (PPP) project," *Res Manageria*, vol. 2, no. 4, pp. 57–65, 2017.

[17] H. Sun, Y. Liang, and Y. Wang, "Grey clustering evaluation for the cooperation efficiency of PPP project: taking Beijing Metro line 4 as an example," *Mathematical Problems in Engineering*, vol. 2019, Article ID 8232731, 13 pages, 2019.

[18] Operation Guide for Government-Social Capital Cooperation Model, 2014.

[19] L. Bai, Y. Li, Q. Du, and Y. Xu, "A fuzzy comprehensive evaluation model for sustainability risk evaluation of PPP projects," *Sustainability*, vol. 9, no. 10, Article ID 1890, 2017.

[20] V. S. K. Delhi and A. Mahalingam, "Relating institutions and governance strategies to project outcomes: study on public–private partnerships in infrastructure projects in India," *Journal of Management in Engineering*, vol. 36, no. 6, 2020.

[21] C. Rao and Y. Gao, "Evaluation mechanism design for the development level of urban–rural integration based on an improved TOPSIS method," *Mathematics*, vol. 10, no. 3, Article ID 380, 2022.

[22] P. Yi, Q. Dong, W. Li, and L. Wang, "Measurement of city sustainability based on the grey relational analysis: the case of 15 sub-provincial cities in China," *Sustainable Cities and Society*, vol. 73, Article ID 103143, 2021.

[23] S. Ye, Y. Chen, and G. Mao, "Weighting of basic indices for value for money qualitative evaluation of the public–private partnership aged care project through the analytic hierarchy process," *Discrete Dynamics in Nature and Society*, vol. 2021, Article ID 1227657, 6 pages, 2021.

[24] B. Liu and F. H. Sun, "Research on the risk assessment method of PPP project based on the improved matter element model," *Scientia Iranica*, vol. 27, pp. 614–624, 2020.

[25] N. Carbonara, N. Costantino, and R. Pellegrino, "Concession period for PPPs: a win–win model for a fair risk sharing," *International Journal of Project Management*, vol. 32, no. 7, pp. 1223–1232, 2014.

[26] I. M. Jiskani, S. Han, A. U. Rehman, N. M. Shahani, M. Tariq, and M. A. Brohi, "An integrated entropy weight and grey clustering method-based evaluation to improve safety in mines," *Mining, Metallurgy & Exploration*, vol. 38, no. 4, pp. 1773–1787, 2021.

[27] A. P. C. Chan, P. T. I. Lam, D. W. M. Chan, E. Cheung, and Y. Ke, "Drivers for adopting public private partnerships—empirical comparison between China and Hong Kong special administrative region," *Journal of Construction Engineering and Management*, vol. 135, no. 11, pp. 1115–1124, 2009.

[28] R. Mu, M. de Jong, and J. Koppenjan, "The rise and fall of public–private partnerships in China: a path-dependent approach," *Journal of Transport Geography*, vol. 19, no. 4, pp. 794–806, 2011.

[29] B. Chen, "Public–private partnership infrastructure investment and sustainable economic development: an empirical study based on efficiency evaluation and spatial spillover in China," *Sustainability*, vol. 13, no. 15, Article ID 8146, 2021.

[30] X. Liu and G. Cao, "The impact of participation in PPP projects on total factor productivity of listed companies in China," *Sustainability*, vol. 13, no. 14, Article ID 7603, 2021.

[31] B. T. B. Eshun and A. P. C. Chan, "An evaluation of project risk dynamics in sino-africa public infrastructure delivery; a causal loop and interpretive structural modelling approach (ISM-CLD)," *Sustainability*, vol. 13, no. 19, Article ID 10822, 2021.

[32] N. Carbonara, N. Costantino, L. Gunnigan, and R. Pellegrino, "Risk management in motorway PPP projects: empirical-based guidelines," *Transport Reviews*, vol. 35, no. 2, pp. 162–182, 2015.

[33] W. Xiong, X. Zhao, J.-F. Yuan, and S. Luo, "Ex post risk management in public–private partnership infrastructure projects," *Project Management Journal*, vol. 48, no. 3, pp. 76–89, 2017.

[34] S. Shijun, "Risk management and countering measurements by computer modeling and simulation technology in the approval and early preparation stages of a large international project," *The Journal of Supercomputing*, vol. 76, no. 5, pp. 3689–3701, 2020.

[35] A. Shrestha, T.-K. Chan, A. A. Aibinu, C. Chen, and I. Martek, "Risk allocation inefficiencies in Chinese PPP water projects," *Journal of Construction Engineering and Management*, vol. 144, no. 4, Article ID 04018013, 2018.

[36] Y. Ke, S. Q. Wang, and A. P. C. Chan, "Risk management practice in China's public–private partnership projects," *Journal of Civil Engineering and Management*, vol. 18, no. 5, pp. 675–684, 2012.

[37] B. Ness, S. Anderberg, and L. Olsson, "Structuring problems in sustainability science: the multi-level DPSIR framework," *Geoforum*, vol. 41, no. 3, pp. 479–488, 2010.

[38] X. Cao and J. Ma, "Study on the improving of capital system of PPP fixed assets investment," *Journal of the Central University of Finance and Economics*, vol. 5, pp. 13–20, 2020.

[39] D. Penyalver, M. Turró, and J. B. Williamson, "Measuring the value for money of transport infrastructure procurement; an intergenerational approach," *Transportation Research Part A: Policy and Practice*, vol. 119, pp. 238–254, 2019.

[40] D. Grimsey and M. K. Lewis, "Evaluating the risks of public private partnerships for infrastructure projects," *International Journal of Project Management*, vol. 20, no. 2, pp. 107–118, 2002.

[41] J. R. Vogel, T. L. Moore, R. R. Coffman et al., "Critical review of technical questions facing low impact development and green infrastructure: a perspective from the great plains," *Water Environment Research*, vol. 87, no. 9, pp. 849–862, 2015.

[42] Y. Xu, A. P. C. Chan, B. Xia, Q. K. Qian, Y. Liu, and Y. Peng, "Critical risk factors affecting the implementation of PPP waste-to-energy projects in China," *Applied Energy*, vol. 158, pp. 403–411, 2015.

[43] S. Zhang, A. P. C. Chan, Y. Feng, H. Duan, and Y. Ke, "Critical review on PPP research—a search from the Chinese and international journals," *International Journal of Project Management*, vol. 34, no. 4, pp. 597–612, 2016.

[44] P. Zhang, K. Zhan, and Y. Zhou, "Game model of three-party shared risk allocation for PPP projects-based on the perspective of incomplete information," *IOP Conference Series: Earth and Environmental Science*, vol. 295, Article ID 042049, 2019.

[45] J. Xia, Y. Y. Zhang, L. H. Xiong, S. He, L. F. Wang, and Z. B. Yu, "Opportunities and challenges of the Sponge city construction related to urban water issues in China," *Science China Earth Sciences*, vol. 60, no. 4, pp. 652–658, 2017.

[46] N. A. A. Karim, "Risk allocation in public private partnership (PPP) project: a review on risk factors," *International Journal of Sustainable Construction Engineering and Technology*, vol. 2, no. 2, pp. 8–16, 2011.

[47] E. Iossa, G. Spagnolo, and M. Vellez, "Contract design in public–private partnerships," Report for the World Bank, 2007.

[48] X. Xing, B. Zhong, H. Luo, H. Li, and H. Wu, "Ontology for safety risk identification in metro construction," *Computers in Industry*, vol. 109, pp. 14–30, 2019.

[49] T. Yan, C. Chen, and G. Li, "Research on risk allocation model in PPP projects based on stakeholder network," 2017.

[50] Y. Mao and Y. Zhang, "Risk identification and allocation of the utility tunnel PPP project," 2017.

[51] L. M. Sastoque, C. A. Arboleda, and J. L. Ponz, "A proposal for risk allocation in social infrastructure projects applying PPP in Colombia," *Procedia Engineering*, vol. 145, pp. 1354–1361, 2016.

[52] T. Sachs, R. Tiong, and S. Q. Wang, "Analysis of political risks and opportunities in public private partnerships (PPP) in China and selected Asian countries: survey results," *Chinese Management Studies*, vol. 1, no. 2, pp. 126–148, 2007.

[53] A. Shrestha, T.-K. Chan, A. A. Aibinu, C. Chen, and I. Martek, "Risks in PPP water projects in China: perspective of local governments," *Journal of Construction Engineering and Management*, vol. 143, no. 7, Article ID 05017006, 2017.

[54] Q. Yang, W. Luan, S. Yu, and J. Chen, "Rotational restraint to purlins provided by standing seam roof systems," *Advances in Civil Engineering*, vol. 2019, Article ID 2709890, 8 pages, 2019.

[55] M. Xu, C. Liu, D. Li, and X. Zhong, "Tourism ecological security early warning of Zhangjiajie, China based on the improved TOPSIS method and the grey GM(1,1) model," *Chinese Journal of Applied Ecology*, vol. 28, no. 11, pp. 3731–3739, 2017.

[56] E. Jokar, B. Aminnejad, and A. Lork, "Assessing and prioritizing risks in public–private partnership (PPP) projects using the integration of fuzzy multi-criteria decision-making method," *Operations Research Perspectives*, vol. 8, Article ID 100190, 2021.

[57] H.-W. Wu, E.-Q. Li, Y.-Y. Sun, and B.-T. Dong, "Research on the operation safety evaluation of urban rail stations based on the improved TOPSIS method and entropy weight method," *Journal of Rail Transport Planning & Management*, vol. 20, Article ID 100262, 2021.

[58] W. Huang, B. Shuai, Y. Sun, Y. Wang, and E. Antwi, "Using entropy-TOPSIS method to evaluate urban raitransit system operation performance: the China case," *Transportation Research Part A: Policy and Practice*, vol. 111, pp. 292–303, 2018.

[59] J. Wang, Z. Sun, and R. Cao, "An efficient and robust Kriging-based method for system reliability analysis," *Reliability Engineering & System Safety*, vol. 216, Article ID 107953, 2021.

[60] M. Gai, J. Zhu, C. Sun, and K. Sun, "Spatial–temporal evolution and influencing factors of marine economic efficiency in coastal areas of China," *Resource Science*, vol. 40, no. 10, pp. 1966–1979, 2018.

[61] F. Y. Huang, "Research on China's regional economic structure and tax revenue growth," Xiamen, PEOPLES R CHINA, 2009.

[62] Y. S. Liang, K. Shi, L. S. Wang, and J. Y. Xu, "Local government debt and firm leverage: evidence from China," *Asian Economic Policy Review*, vol. 12, no. 2, pp. 210–232, 2017.

[63] Ministry of Finance, "Notice on regulating the project library management of government and social capital cooperation (PPP) integrated information platform (No.92 [2017] of finance office)," 2017.

[64] Y. Lin, "Look forward to the future from the development history of PPP in China," 2014, Retrieved 8-23, 2015, from http://opinion.caixin.com/2014-08-01/100712038_all.html#page2.

[65] Y. Wang, K.-H. Tan, and J. Zhang, "Influencing factors and spatial spillover effect of infrastructure PPP Financing Model," *Journal of Transportation Systems Engineering and Information Technology*, vol. 21, no. 4, pp. 47–53, 2021.
[66] Y. Feng, X. Guo, B. Wei et al., "A fuzzy analytic hierarchy process for risk evaluation of urban rail transit PPP projects," *Journal of Intelligent & Fuzzy Systems*, vol. 41, no. 4, pp. 5117–5128, 2021.
[67] Z. Liu, Y. Jiao, A. Li, and X. Liu, "Risk assessment of urban rail transit PPP project construction based on Bayesian network," *Sustainability*, vol. 13, no. 20, Article ID 11507, 2021.
[68] Y. Zhang, N. He, Y. Li, Y. Chen, L. Wang, and Y. Ran, "Risk assessment of water environment treatment PPP projects based on a cloud model," *Discrete Dynamics in Nature and Society*, vol. 2021, Article ID 7027990, 15 pages, 2021.