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Research on the Structural Features and Influential Factors of the Spatial Network of China's Regional Ecological Efficiency Spillover

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Abstract: A regional coordinated development strategy is an important measure that is often used to implement sustainable development in China. However, many obstacles greatly limit the realization of regional ecological coordinated sustainable development. In this paper, ecological efficiency is utilized as an important indicator of sustainable development, and the network analysis method is used to explore the spatial correlation relationship of regional ecological coordinated sustainable development. This paper calculates the ecological efficiency of each region using the Window slacks-based measure (Window-SBM) model, formulates the spatial network of regional ecological efficiency spillover through the vector auto-regressive (VAR) Granger causality model, and analyzes the spatial spillover relationship and influencing factors of regional ecological efficiency by using the social network analysis method. It is found that the spillover network of ecological efficiency in each region presents a typical core-edge structure. In addition, there is an obvious hierarchical structure among blocks with different directions and functions. Industrial structure, economic development, and geographical proximity have a positive impact on the spatial spillover of regional ecological efficiency, while environmental regulation has a negative impact. Finally, relevant policy suggestions are put forward.

Keywords: ecological efficiency; Window-SBM; spatial spillover; spatial network structure

1. Introduction

In recent years, ecological problems, including global warming, pollution of air and fresh water resources, land degradation, losses of forest resources, cross-border transfer of hazardous wastes, and shape decrease of species diversity, have become increasingly prominent. Policymakers are forced to pay increased attention to ecological effect problems including environmental degradation, resource exhaustion, and climate change effects on economic activities (Lansink et al., 2014) [1]. This is especially true for developing countries, China being no exception. Since China's reform and opening-up economic development policies were first initiated, part of the administrative power of China has gradually been delegated. Thus, China's economy has obtained constantly rapid growth for over 30 years. However, because of this extensively high growth, along with traditional thinking concerning GDP, the concept of "promotion tournament" has caused a major waste of environmental resources and a continuously deteriorated ecological environment, which seriously hinders the sustainable development of the economy and society. In recent years, Chinese governments, at all levels, have formulated a series of laws, regulations, and policies related to environmental protection, and constantly increased investment has been made in environmental governance. In 2017, the total investment amount for the governance of environmental pollution reached 953.9 billion yuan, accounting for 1.16%

of GDP for that year. Generally speaking, the ecological environmental quality of China continues to be improved; however, the effect of this improvement is not steady. In the 1st–9th rounds of the supervision process of enhanced supervision for key regions, which were included in the Blue Sky Protection Campaign by the Ministry of the Ecological Environment, 19,442 environmental issues were found. In the opinion of Li and Cheng et al. [2,3], the result is that, under the combined actions of a decentralized governance structure and a performance appraisal mechanism, there exists an act of "race to the bottom" among local governments in environmental regulation, for which the ecological efficiency of various places in China presents a significant spatial non-balance with obvious spatial spillover features and a significant proximity effect. Meanwhile, under the dual forces of regional coordinated development strategy and market mechanism, the spatial correlation of regional ecological efficiency is promoted to present a systematic and complex network structural form. A series of new regional coordinated development strategies have been put forward in the report of the 19th Communist Party of China National Congress. However, in the new era, what kind of structural characteristics does the spatial spillover correlation network of regional ecological efficiency in China present? What are the blocks with different functions? What are the mechanisms of ecological efficiency spillover? What are the key factors affecting the spillover? It is of great theoretical and practical significance to find out the answers to these problems in order to explore regional differentiation transformation, narrow the regional ecological gap, strengthen urban ecological cooperation, and further promote regional coordinated development and sustainable development. Therefore, this paper uses the network analysis method to explore the overall characteristics of the spatial spillover correlation of regional ecological efficiency, clarify the regional ecological efficiency of spillover blocks and its spillover mechanism, and accurately find the key influencing factors of the spatial correlation of regional ecological efficiency spillover. Based on this, some policy recommendations about how to effectively promote the spatial spillover correlation of regional ecological efficiency and enhance the ability of regional coordinated development are put forward for the purposes of providing reference for the government and its relevant departments in decision-making.

The rest of this paper is arranged as follows. The second part is a literature review, which investigates and comments on the literature of ecological efficiency and its spillover, and also outlines the basic ideas and research purposes of this paper. The third part is the research method and data processing, which includes construction of the empirical model and the description of variable selection and data collection and processing. The fourth part is the empirical analysis and discussion of the results. The fifth part is the conclusion and policy recommendations.

2. Literature Review

The idea of ecological efficiency was first put forward by the German scholars Schaltegger and Stum, and it reflects the relationship between economic development and the utilization of resources and environment, provides a new research idea for solving the contradiction between environment and regional development, and is an important indicator of the comprehensive reflection of urban sustainable development. Since then, international institutions and scholars have enriched its connotations from different perspectives [4]. The Organization for Economic Co-operation and Development (OECD) defines ecological efficiency as the ratio of input to output, with the aim of achieving more valuable outputs with less resources (Lehm, 2000) [5]. From the viewpoint of meeting the needs of human development, the World Business Council on Sustainable Development (WBCSD) defines it as the provision of competitive products or services with a reduced impact on the environment to the extent that the earth can meet the basics of human needs and quality of life [6]. From the viewpoint of reducing natural resource investment, the European Environment Agency (EEA) considers ecological efficiency as the creation of more benefits with the least natural investment, while the Economic and Social Commission for Asia and the Pacific (ESCAP) considers it as an important element that can be utilized to improve basic social productivity and reduce resource consumption [7,8]. From the viewpoint of reducing environmental damage, the UN Conference on

Trade and Development (UNCTAD) see ecological efficiency as something that will increase (or at least not reduce) shareholder value while reducing environmental damage [9]. Picazo Tadeo et al. (2012) [10] believe that ecological efficiency means that enterprises, industries, or economies reduce their impact on the environment while producing goods and services. Although ecological efficiency lacks a unified academic definition, the core connotation of ecological efficiency refers to the production of the maximum amount of competitive products or services by using the least amount of resources, while producing the smallest amount of environmental pollutants such as wastewater, waste gas, and solid waste in the process. This basic concept will help in the development of new research ideas for solving conflicts between resources and the environment and regional development.

Regions which are not separated in the space will have mutual effects with other regions, especially with proximal areas, causing the spatial spillover effect. Many scholars conducted empirical analysis on spatial differences and influences of ecological efficiency among regions by using the spatial statistical model. The study of Wang et al. (2018) [11] shows that the regional ecological efficiency is progressively decreased from developed cities to less developed cities, as well as from the eastern region to the middle and western regions, which has an obvious phenomena of "club convergence" and significant spatial correlation and clustering. Guan and Xu (2016) [12] pointed it that the ecological efficiency of China's energy has obvious global and local spatial agglomeration feature, high-high agglomeration mainly occurs in the eastern and southern coastal regions, northwest region and the midstream of the Yellow River. The spatial pattern is changed mainly in high-low, low-high agglomeration regions, particularly in the Beijing-Tianjin-Hebei Region. Bai and Deng (2018) [13] who takes the prefecture-level city as the research object completed some research on the influence of urbanization on ecological efficiency and regional differences by building a spatial econometrics and threshold panel model. The research results show that the urban ecological efficiency spillover effect of China is quite obvious.

Competition is the common mechanism of mutual effect among regions [14–17]. The existing literature has proved that local governments interact and influence each other in both developed and developing countries. The policies and behaviors of local governments are related to their neighboring areas, which are often reflected as a competition for economic development and environmental regulation. Driven by the competitive mechanism, regional ecological efficiency spillover effect has a spatial relevance. In general, opinions of scholars can be divided into two types. The first type is "race to the bottom". In order to guarantee that local enterprises can obtain competitive advantages in the financial decentralization system or attract enterprises from other regions, local governments are likely to reduce the operating cost of enterprises and promote the competitiveness of local enterprises by lowering the environmental discharge standard. However, environmental pollution will be aggravated, and the effect of "pollution havens" will spread through local places, which will not be beneficial for promoting urban ecological efficiency [18,19]. These behaviors also can be simulated by governments in proximal areas. Zhou and Wang et al. (2018) [20] pointed that the influence on regional economic efficiency is negatively enhanced by economic competition between governments when there is high fiscal decentralization promoted by the national government. Wang (2018) [21] researched the influence of direct investment made by foreign merchants on regional economic efficiency from the perspective of the third-country effect by applying Data Envelopment Analysis (DEA) and the spatial econometric analysis method. The result shows that, compared with the third-country effect, there are more significant changes on ecological efficiency caused by FDI. FDI which is flowing into the eastern region and proximal regions will cause significantly positive influences on the ecological efficiency of those regions. In the western region, FDI accumulation of proximal regions causes increased regional ecological efficiency with significantly positive changes; however, its significance level is lower than that of the non-third-country effect, and the elasticity coefficient also becomes smaller. However, compared with the local region, proximal regions have their quite low ecological efficiency, thus that local region is faced with relatively large development pressure. When a "promotion tournament" occurs, the region not only treats proximal regions as competitors, but also treats larger regions and nationwide advanced cities as competitive benchmarks, which is helpful for promoting ecological

efficiency [22]. The second type of relevant behavior is a "benchmark competition". This kind of competition occurs when the central government adds clear conditions involving the improvement of environmental quality into their assessment system for the promotion of officials, or when a "vote by feet" process is used by citizens to improve the supply level of ecological products and services of their local governments [23,24].

Driven by the spatial spillover effect, the dynamic correlation of the regional ecological efficiency spillover effect includes structural information, thereby presenting the network structure. On the one hand, governmental regulation and market mechanisms have promoted the integration of inter-regional economic elements. Regardless of the freedom flow of production elements including inter-regional labor force and assets, or the knowledge spillover caused by economic activities including freedom transaction of technologies and commodities as well as information exchange, countless economic correlations among regions are introduced. The "anchor point" of the Chinese regional development strategy lies in interactions between coastal regions and inland areas as well as the coordinated development of east-central-west regions. While these regions are not likely to be geographically proximal, they are in fact correlated in economic growth. Therefore, there exist some spatial correlations for inter-regional economic growth in China, which are relatively complex and involve the features of networking [25]. Li and Chen (2014) [26] have deconstructed the spatial association features of regional economic growth by applying the network analysis method and Quadratic Assignment Procedure (QAP) method, and find that the spatial network of Chinese regional economic growth has multiple superpositions involving stability. On the other hand, under the joint functions of environmental regulations, endowment of resources, and technology spillover, the spatial association of inter-regional environmental pollution has surpassed the pure proximal or neighboring relations geographically, thereby presenting a complex networking structure (Liu Huajun, etc., 2017 [27], 2018 [28]; Wang and Ye et al., 2019 [29]; Lv, Kangjuan, et al. 2019 [30]). Song and Feng (2019) [31] et al. investigated the spatial structural pattern and correlation effect of carbon dioxide of a region by using social network analysis in an empirical study. Economic growth and environmental pollution are the core connotations of ecological efficiency; therefore, inter-regional ecological efficiency spillover also has some network structures.

In conclusion, the existing research on the basis of exploratory spatial data analysis (ESDA) reveal the significant spatial correlation and spatial agglomeration feature of China's regional ecological efficiency. However, traditional spatial measurement methods are based on the "attribute data" instead of "relational data", which only can observe the "quantity" effect of regional ecological efficiency on the basis of taking spatial factors into consideration, but cannot reveal the influential effect of the "relation" of the spatial correlation of regional ecological efficiency spillover, thus it is hard to describe the overall network structure characteristics of the spatial correlation of regional ecological efficiency spillover, while the structure often indicates the expression of attribute dates when more analysis values are used [32]. Social network analysis provides a feasible tool for revealing the characteristics of network structure. This method takes "relation" as the basic unit and describes the relation mode with the tool of graph theory tools and the technology of algebraic model, which is an interdisciplinary analysis method used for "relation data". The paper is based on a focus on the relational date and network, in which the regional ecological efficiency is evaluated by taking advantage of the panel data of provinces in China from 1998 to 2016 and adopting an undesirable output-oriented Window slacks-based measure (window SBM) model. In addition, the spatial correlation relation of inter-regional ecological efficiency spillover is determined by building an vector auto-regressive (VaR) Granger causality model, and the spatial network structure and influential effect of regional ecological efficiency spillover are investigated again by using Social Network Analysis (SNA). The overall feature and evolution trend of correlation network of regional ecological efficiency spatial spillover can be reflected by measuring the Density, Connectedness, Hierarchy and Efficiency of the network; the roles and functions of various provinces in the correlation network of regional ecological efficiency spatial spillover can be investigated by examining the network's Centrality; the spatial clustering method of regional ecological spillover can

be revealed by using Block Modeling, and influential factors on the correlation network structure of regional ecological efficiency spillover have been tested in the empirical test.

3. Research Method and Data

3.1. Evaluated Model and Method of Regional Ecological Efficiency

The Evaluated efficiency model has two forms: a parametric method and a non-parametric method. The types of Non-parametric methods include the DEA model, and includes the integer DEA model [33], super-Efficiency DEA model [34,35], cross efficiency DEA model [36], multi-stage DEA model [37,38], undesired SBM model [39], etc. The Parametric model is Stochastic Frontier Analysis (SFA). This model's advantages lie in that it can not only take stochastic disturbance into consideration, but can also analyze potential fungibility between environmental pressures (Orea L and Wall, 2017 [40]). However, the SFA model has a definite function, which may lead to inaccurate estimated results due to mistaken establishment of the function form. In this paper, because the definition of ecological efficiency, the SBM model of undesired output proposed by Tone was selected. This decision was made so relationships between input, output, and pollution can be considered comprehensively and dealt with, meaning the relaxation problem of efficiency evaluation can be more effectively solved. In the SBM model of undesired output, it is assumed that the production system has J decision units, where each decision unit can be distinguished as I types of input (x), S_1 types of desired output (y^g) and S_2 types of undesired output (y^b), while matrixes of X, Y^g, and Y^b are defined as $X = [x_1, x_2, \ldots x_n]$, $Y^g = [y_1{}^g, y_2{}^g, \ldots y_n{}^g]$, and $Y^b = [y_1{}^b, y_2{}^b, \ldots y_n{}^b]$, where x, y^g, and Y^b as the input, desired output, and undesired output are greater than 0. As a result, under the unchanged returns to scale, the production rate can be obtained and expressed as $P = \{(x, y^g, Y^b) | x \geq X\lambda, y^g \leq Y^g\lambda, Y^b \leq Y^b\lambda\}$. The SBM model of undesired output [41] isis:

$$\begin{aligned} Min: \rho \quad &= \frac{1-\frac{1}{s+q}\left(\sum_{i=1}^{s}\frac{s_i^-}{x_{ik}}+\sum_{l=1}^{q}\frac{s_l^b}{y_{lk}^b}\right)}{1+\frac{1}{m}\sum_{r=1}^{m}\frac{s_r^g}{y_{rk}^g}} \\ s.t. \quad &\sum_{j=1}^{n}\lambda_j x_{ij} = x_{ik} - s_i^-, i = 1, \ldots, s. \\ &\sum_{j=1}^{n}\lambda_j y_{rj}^g = y_{rk}^g + s_r^g, r = 1, \ldots, m. \\ &\sum_{j=1}^{n}\lambda_j y_{lk}^b = y_{lk}^b - s_l^b, l = 1, \ldots, q. \\ &s_i^-, s_r^g, s_l^b \geq 0. \\ &\lambda_j \geq 0, j = 1, \ldots, n. \end{aligned} \tag{1}$$

where, s is the relaxation quantity of the input and output, λ is the weight vector, the objective function is in relation to S^-, S^b, and S^g, and the value of this function is between 0 and 1. x_{ij}^t is input of i item of the jth DMU, y_{rj} is the output of the jth r item. With regard to the decision unit, when its value is 1, that is, S^-, S^b, and S^g are equivalent, the decision unit is valid. Otherwise, the decision unit is inefficient or there is an efficiency loss, and the relation between input and output still needs to be improved. This is because the figure that can be measured by the SBM is the static efficiency value, which cannot reflect the variation trend of the ecological efficiency of various provinces in time series; therefore, this value is needed to build a DEA window model of ecological efficiency on the basis of the SBM model as follows [42]:

$$
\begin{aligned}
&Min:\rho=\frac{1-\frac{1}{s+q}\left(\sum_{i=1}^{s}\frac{s_i^{-,th}}{x_{ik}^{th}}+\sum_{t=1}^{q}\frac{s_t^{b,th}}{y_{tk}^{b,th}}\right)}{1+\frac{1}{m}\sum_{r=1}^{m}\frac{s_r^{g,th}}{y_{rk}^{g,th}}}\\
&s.t.\sum_{j=1}^{W\times J}\lambda_j^{th}x_{ij}^{th}=x_{ik}^{th}-s_i^{-,th},i=1,...,s.\\
&\sum_{j=1}^{W\times J}\lambda_j^{th}y_{rj}^{g,th}=y_{rk}^{g,th}+s_r^{g,th},r=1,...,m.\\
&\sum_{j=1}^{W\times J}\lambda_j^{th}y_{tk}^{b,th}=y_{tk}^{b,th}-s_t^{b,th},t=1,...,q.\\
&s_i^{-,th},s_r^{g,th},s_t^{b,th}\geq 0.\\
&\lambda_j^{th}\geq 0,j=1,\ldots,W\times J\\
&t=1,2,...,(T-W+1),\ h=1,2,...,W
\end{aligned}
\tag{2}
$$

The variables in the model above, named the Window-SBM Model, are the same as the ones in the SBM model. Here, t and h are the variables on the tth time-point of the hth window. When $J = 30$ and $W = 3$, the average efficiency on various time-points can be determined by using the moving average method, which provides the efficiency value that can be compared by the evaluation unit in a time series.

3.2. Method of Spatial Correlation of Regional Ecological Efficiency Spillover

Through analysis on existing literature, the network relation was determined mainly by using test methods such as the gravity model and VAR Granger Causality. We selected the VAR model to build the network spatial correlation structure of regional ecological efficiency, defined the time series of ecological efficiency of two areas respectively as $\{x_t\}$ and $\{y_t\}$, and built two VAR models to test whether the ecological efficiency of two areas has Granger causality or does not [43]:

$$x_t=\alpha_1+\sum_{i=1}^{m}\beta_{1,i}x_{t-i}+\sum_{i=1}^{n}\gamma_{1,i}y_{t-i}+\varepsilon_{1,t} \tag{3}$$

$$y_t=\alpha_2+\sum_{i=1}^{p}\beta_{2,i}x_{t-i}+\sum_{i=1}^{q}\gamma_{2,i}y_{t-i}+\varepsilon_{2,t}. \tag{4}$$

In the formula, α_i, β_i, γ_i (i = 1, 2) are the parameters that need to be estimated; ε_i (i = 1, 2) is the residual term, following the standardized normal distribution; m, n, p, and g are lag orders of autoregression. If the test result is the Granger causality between the A area and the B area, it shows that there is a significant spatial correlation effect of the A area on the B area; the rest of the process can be completed in the same manner to build a spatial correlation network of regional ecological efficiency.

3.3. Variables and Data

According to the connotation of ecological efficiency, regional ecological efficiency comprehensively reflects the win-win relationship between resource conservation, environmental protection, and economic growth. Therefore, based on the existing research [44–48], we chose energy consumption, human consumption, water resource consumption, and assets input as the input indicators for this paper. Among these inputs, ten thousand yuan GDP consumption was taken as the proxy variable of energy consumption, quantity of employment at the end of the year in each province as the proxy variable of human consumption, and the total consumed water in each region as the proxy variable of water consumption. When measuring assets input, scholars mostly choose capital stock as the proxy variable of capital investment. Combined with the availability of data, this paper selected the total investment amount of fixed assets in each region as the proxy variable of capital. In order to

eliminate the influence of price factors, the capital stock of the following years was estimated by using the perpetual inventory method based on 1995 as the input index.

The output indicators were mainly divided into a desired output and undesired output, and scholars usually choose the total amount of economic development as the proxy variable of desired output. In order to eliminate the influence of price factors, the GDP index of different provinces was deflated based on 1995.

Undesired outputs mainly refer to the environmental pollution generated in production activities, including exhaust gas, wastewater, and solid waste. The amount of discharged wastewater and chemical oxygen demand in wastewater were selected as the proxy variables of the wastewater discharge. The SO_2 discharge amount, and volume of soot emission were selected as the proxy variables of waste gas discharge. Finally, industrial solid discharge was selected as the proxy variable of solid waste discharge. See Table 1 for further details of this index system.

Table 1. Index System of Ecological Efficiency.

Index	Specific Indexes Constitution	Definition
Input of resources	Energy consumption	Ten thousand yuan GDP consumption
	Water resources consumption	Total consumed water
	Human consumption	Quantity of employment
	Assets input	Total investment amount of fixed assets
Desired output	Total amount of economic development	Per capita GDP
Undesired output	Wastewater discharge	Discharge amount of wastewater
		Chemical oxygen demand (cod) in wastewater
	Exhaust gas discharge	SO_2 discharge amount
		Volume of soot emission
	Solid waste discharge	Industrial solid discharge

The influential factors of regional ecological efficiency spillover are mainly involved in the following two aspects: on the one hand, regional differences are important factors with influence on the spatial correlation compact degree (Pan Wenqing, 2012; Liu Huajun, 2015) [49,50] and on the regional ecological efficiency spillover; on the other hand, proximal provinces tend to have relatively strong correlations [51]. The ecological efficiency of some provinces may affect that of other provinces that are close to them, meaning the regional ecological efficiency spillover effect will be stronger in these cases. Therefore, in this paper, the influential factors of correlation network structure of regional efficiency spillover are considered using two dimensions: geographical proximity and regional differences. While referring to the existing research, the geographic connection matrix was selected as the proxy variable of geographical proximity, while the economic development level, industrial structure, freedom degree of investment, environmental regulation, and technical improvement were selected as influential factors of regional differences on the spatial correlation relation of regional ecological efficiency spillover [52–56]; see Table 2 for further details.

Due to the lack of data in Tibet, this paper uses 30 provinces in China (excluding Hong Kong, Macao, and Taiwan) as network nodes to empirically analyze the spatial correlation of regional ecological efficiency. The sample period spans from 1998 to 2016. Data were collected from the "China Statistical Yearbook", "China Energy Statistics", "China Environmental Yearbook", and provincial and Municipal Statistical yearbooks. The original data for GDP, employment figures, water use, industrial structure, investment openness, and technological progress were from the "China Statistical Yearbook" and statistical yearbooks from the provinces and cities, while the original data of undesired outputs and environmental regulation were from the "China Environmental Yearbook", and the original data on energy consumption were from the "China Energy Statistical Yearbook".

Table 2. Variables of Spatial Correlated Influential Factors of Ecological Efficiency Spillover.

Influential Factors	Variables	Definition
Geographical proximity X_1	Geographical Proximity (GP)	Geographical proximity matrix (W_{ij}^{G}); in the case of two areas, i and j, with a common geographic boundary, the matrix assignment will be 1 because they are proximal; if they are not proximal, then the assignment is 0
	Economic Development Level (EL)	Per capita GDP
Regional difference X_2	Industrial Structure (IS)	Proportion of industrial value added of various provinces accounting for total output value
	Freedom Degree of Investment (FDI)	Actual foreign direct investment expressed in RMB accounting for gross regional production
	Environmental Regulation (ER)	Proportion of investment in industrial pollution control accounting for the industrial value added
	Technical Improvement (TI)	R&D input intensity

4. Spatial Correlation Network Characteristics of Regional Efficiency Spillover

4.1. Spatial Distribution Pattern of Regional Ecological Efficiency

In this paper, China's regional ecological efficiency is measured by taking advantage of the window DEA model in the preceding part of the text and using MAXDEA Pro 6.4 with the results from Table 3. On the whole, the regional ecological efficiency of most of provinces in our country was zero for a long time. Within the investigation period of samples, the mean value of ecological efficiency of the eastern region is between 0.729 and 0.963, while that of the central region is between 0.606 and 0.775; in the western region, the value is between 0.586 and 0.65. The ecological efficiency among the eastern, central, and western regions is significantly different (in Figure 1). In order to further understand the provincial and regional differences of Chinese regional efficiency, in the paper, we took the year 2016 as an example, and the spatial distribution tendency of China's regional ecological efficiency was visually described by using the tendency analysis tool of ArcGIS. As shown in Figure 2, the Z axis represents the value of regional ecological efficiency, X is the west-east direction, and Y is the south-north direction. The inverted-U trend line shows that China's regional ecological efficiency has significant regional differences in space. In the east-west direction, the ecological efficiency of the eastern region is higher than that of the western region; in the south-north direction, the ecological efficiency of the southern region is higher than that of the northern region, presenting a significant feature of spatial non-balance.

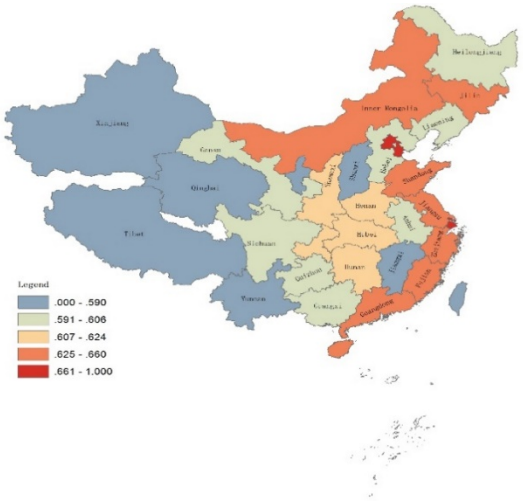

Figure 1. The Distribution Pattern of China's Regional Ecological Efficiency.

Table 3. China's Regional Ecological Efficiency from 1998 to 2016.

Year	1998	2004	2010	2016	Year	1998	2004	2010	2016
Beijing	0.795	0.827	1.000	1.000	Jiangxi	1.000	0.607	0.600	0.585
Tianjin	1.000	0.815	0.934	1.000	Henan	0.689	0.687	0.619	0.617
Hebei	0.659	0.661	0.617	0.606	Hubei	0.706	0.676	0.620	0.624
Liaoning	0.772	0.634	0.622	0.606	Hunan	1.000	0.631	0.609	0.618
Shanghai	0.815	0.831	0.862	1.000	MVMR	0.775	0.680	0.617	0.613
Jiangsu	0.800	0.773	0.675	0.647	Guangxi	0.621	0.593	0.559	0.602
Zhejiang	0.831	0.797	0.684	0.660	Chongqing	0.679	0.607	0.615	0.620
Fujian	1.000	0.876	0.633	0.635	Sichuan	0.642	0.609	0.611	0.605
Shandong	1.000	0.709	0.665	0.636	Guizhou	0.591	0.584	0.599	0.603
Guangdong	0.865	0.837	0.733	0.658	Yunnan	0.667	0.628	0.614	0.579
Hainan	1.000	0.909	0.704	0.642	Shaanxi	0.631	0.610	0.624	0.621
MVEA	0.870	0.788	0.743	0.743	Gansu	0.639	0.609	0.608	0.598
Shanxi	0.622	0.591	0.603	0.587	Qinghai	0.652	0.615	0.581	0.580
Inner Mongolia	0.674	0.619	0.651	0.645	Ningxia	0.608	0.569	0.549	0.577
Jilin	0.676	0.649	0.619	0.635	Xinjiang	0.686	0.629	0.595	0.590
Heilongjiang	0.770	1.000	0.623	0.603	MNWR	0.642	0.605	0.596	0.598
Anhui	0.822	0.645	0.614	0.605	Mean value	0.760	0.687	0.635	0.632

Note: MVEA is the Mean value of the eastern region; MVMR is the Mean value of the middle region; MVWR is the Mean value of the western region.

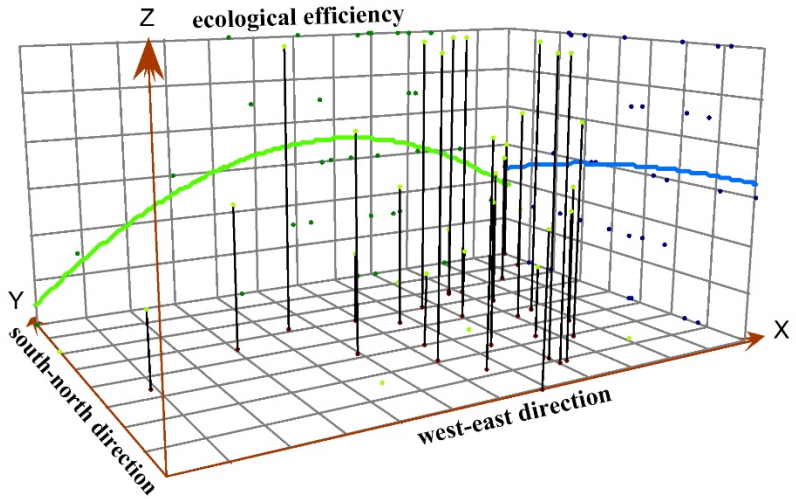

Figure 2. Spatial Evolution Tendency of China's regional ecological efficiency.

4.2. Correlation Network Structural Features of Regional Ecological Efficiency

4.2.1. Overall Feature of the Network

In this paper, based on the VAR model, the spatial correlation relation of regional ecological efficiency was determined and the matrix of relation was established. In order to present the spatial correlation network structure form of ecological efficiency, Netdraw, a visual tool of UCINET, was used to draw the network map of regional ecological efficiency (in Figure 3). It can be seen from Figure 1 that the spatial spillover relation of China's regional ecological efficiency presents a typical network structural form. In other words, the ecological and economic changes of one province are not only affected by factors such as the economic development level, energy consumption, and environmental policies of the province, but also are influenced by other provinces. This kind of mutual influence surpasses the "neighborhood" or "proximal" effect in a purely geographical sense; for instance, changes in the ecological efficiency of Beijing are not only affected by the proximal provinces (Tianjin, Hebei), but also may be influenced by provinces with a longer distance (Jiangsu, Shanghai). There may be a certain kind of spillover relation in changes to the ecological efficiency of proximal provinces or provinces

that are further away, which will bring challenges to the formulation of economic and environmental protection policies that are balanced with development policies. Therefore, opportunities which are created by sources of ecological efficiency spatial spillover on the implementation of inter-regional coordinated development polices were explored using the two dimensions of regional difference and the geographical proximity effect.

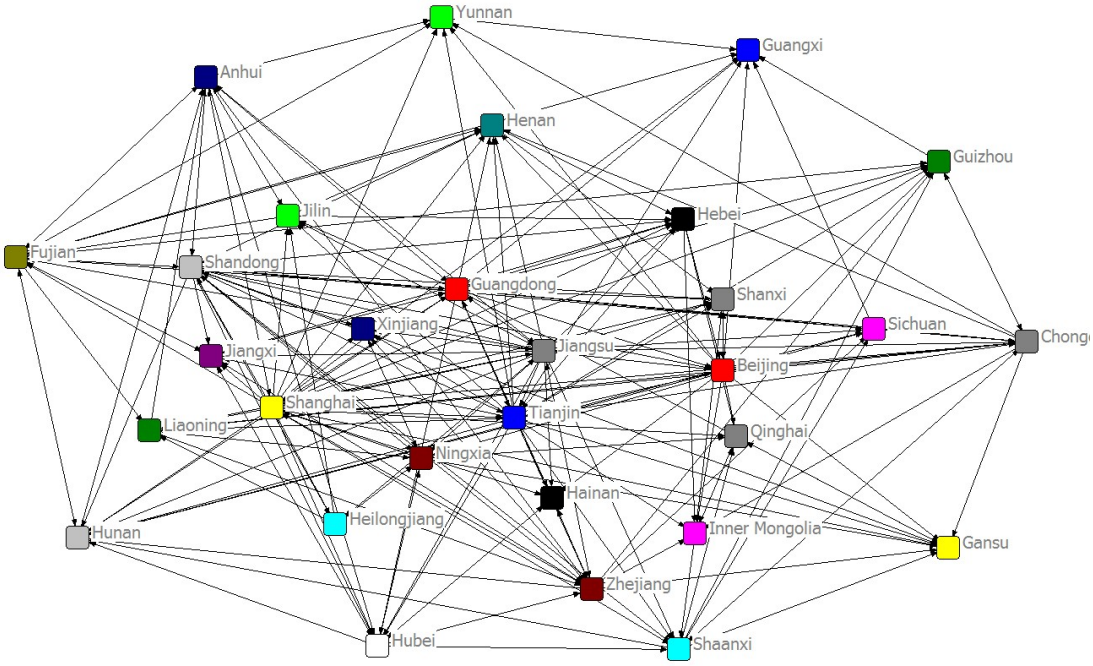

Figure 3. Spatial Correlation network of China's Regional Ecological Efficiency.

However, as seen from the numerical value, the compact degree of China's regional ecological efficiency spatial spillover is not very high. The total number of the maximum possible relation among all provinces is 870 (30 × 29), while the actual relation number of regional ecological efficiency within the observation period is only 230. Therefore, there is a quite large space for the correlation of ecological efficiency spatial spillover among regions. Meanwhile, although the higher network density shows that the correlation of regional ecological efficiency spatial spillover becomes closer and closer, as the network density is continuously promoted, there might be increased redundant connection lines in the network. Once the capacity of network is surpassed, the overall ecological efficiency spillover effect is reduced. Thus, the inhibiting effect is caused for resources allocation and factor mobility. Therefore, the integrated network density must have been maintained. As a result, the spatial optimized pattern of ecological efficiency can be guaranteed.

Through analysis on the rest of the indexes of the overall network features of China's regional ecological efficiency spatial spillover, there exists a significant correlation effect among China's regional ecological efficiency spatial spillovers. Since the network correlation degree is 1, this shows that various provinces are in the correlation network of China's regional ecological efficiency spatial spillover with relatively good connectedness among network nodes, meaning there is a significant spatial spillover effect among China's regional ecological efficiency. The network hierarchy is 0, which shows that there is no obvious gradient in the spatial spillover network of China's regional ecological efficiency, and that any province may have spillover effects on other provinces. The network efficiency is 0.63, which shows that there are many redundant connection lines in the network of China's regional ecological efficiency spatial spillover. This in turn shows that the spatial spillover effect among China's regional ecological efficiency has a significant superposition phenomenon, strengthening the connectedness and stability of the network. This may indicate that as the process of marketalization is accelerated, administrative barriers are gradually broken, and the market plays the stronger leading role in the

process of resources allocation. Thus, communication and cooperation between all places in the domains of energy, trade, and technology are enhanced, the correlated channels of inter-provincial ecological efficiency spatial spillover are increased, and the stability of the spatial spillover network of China's regional ecological efficiency is strengthened.

4.2.2. Centrality Analysis

Through analysis on the measurement of degree centrality, closeness centrality, and betweenness centrality, the positions and roles of various provinces in the correlation network of ecological efficiency spatial spillover are observed and disclosed.

Degree Centrality

Degree centrality represents the beneficial correlations among nodes in the network, which was divided into an in-degree and an out-degree [57]. The larger numerical value of the in-degree shows that the province and city have a larger number of correlations with other provinces and cities in the network, and the larger numerical value of out-degree shows the province has a more significant ecological efficiency spillover effect on other provinces. As shown in the measurement results of degree centrality in Table 4, the average value of degree centrality of the 30 provinces nationwide is 41.609. There are 9 provinces with a degree centrality that is higher than the mean value: Shanghai, Jiangsu, Tianjin, Guangdong, Shandong, Beijing, Zhejiang, Fujian, and Chongqing in a sequence from highest to lowest. These regions have a larger number of correlations with other regions in the correlation network of ecological efficiency spatial spillover. These provinces are mainly located in southeastern coastal areas with relatively good economic development levels and high ecological efficiency. The degree centrality of Shanghai reaches 89.655 at its maximum, which is because the spillover correlation of the regional ecological efficiency of Shanghai has a spatial correlation with 25 provinces, showing that Shanghai enjoys the central position in the spatial spillover correlation network of China's regional ecological efficiency. Provinces with a degree centrality that is higher than the mean value are located in coastal areas except for Beijing and Chongqing, showing that coastal areas have very strong influences on the spatial spillover correlation of overall ecological efficiency in China. However, according to the measurement results of Table 3, the degree centrality ratings of Hainan, Yunnan, Qinghai, Heilongjiang, and Xinjiang occupy the last five positions nationwide, showing that the spatial spillover of ecological efficiency of these regions has less correlation with other regions. The reasons for this are possibly their quite small economic scales and relatively remote geographical locations. Thus, their ecological efficiency spatial spillover has a worse spatial correlation with other provinces.

The degree centrality ranking shows that, compared with other provinces, a selected province plays a certain influential role in the spatial spillover network of China's regional ecological efficiency. The higher out-degree and lower in-degree values reflect that a province has a higher or lower spillover effect on the ecological efficiency of other provinces with core positions in the spatial spillover correlation network of regional ecological efficiency. Provinces with core positions in the correlation network are mainly located at the coastal areas of Circum-Bohai Sea, Yangtze River Delta and Pearl River Delta and have more developed economies and more advanced technology. As seen from the perspective of technical spillover, these regions tend to have a larger technical spillover effect than areas with relatively lower ecological efficiency. Provinces with a lower ranking of out-degree mainly include Guangxi, Yunnan, Xinjiang, Shanxi, and Gansu. A lower out-degree value and higher in-degree values indicate that these provinces mainly receive spillover correlations from other provinces in the spatial spillover correlation network of China's regional ecological efficiency, meaning they are greatly affected by other provinces. It may be that these provinces have relatively slow economic development, low ecological efficiency, and quite remote geographical locations, which is why these areas have relatively serious ecological pollution. Thus, these provinces tend towards passive acceptance of a relatively worse spillover ability of ecological efficiency. The spillover and acceptance relation of the spatial correlation network of ecological efficiency for the 30 regions studied nationwide is

shown as Figure 4. The spillover correlation provided externally by the ecological efficiency of the southeastern coastal areas is greatly strong than the correlated efficiency signals that they receive, while the correlation between the western provinces and other provinces is dominated by an acceptance of efficiency spillover from those other provinces.

Table 4. Network Central Analysis on the Spatial Correlation of Regional Ecological Efficiency.

Provinces	Degree Centrality		Closeness Centrality		Betweenness Centrality			
	Out-Degree	In-Degree	Centrality	Sorting	Centrality	Sorting	Centrality	Sorting
Beijing	14	6	58.621	6	70.732	6	4.417	6
Tianjin	20	7	75.862	3	80.556	3	7.401	2
Hebei	7	7	37.931	13	61.702	13	1.214	12
Shanxi	2	8	27.586	23	58	23	0.267	26
Inner Mongolia	3	7	27.586	24	55.769	28	0.668	19
Liaoning	5	6	34.483	16	60.417	16	1.024	13
Jilin	4	7	31.034	19	59.184	19	0.533	21
Heilongjiang	4	3	20.69	29	54.717	30	0.178	28
Shanghai	25	5	89.655	1	90.625	1	13.064	1
Jiangsu	21	8	79.31	2	82.857	2	7.348	3
Zhejiang	13	9	51.724	7	67.442	7	3.247	7
Anhui	9	7	37.931	14	61.702	14	0.904	14
Fujian	11	9	44.828	8	63.043	9	1.736	9
Jiangxi	4	8	31.034	20	59.184	20	0.233	27
Shandong	16	11	68.966	5	76.316	5	5.096	5
Henan	3	9	37.931	15	61.702	15	0.509	23
Hubei	6	10	41.379	10	63.043	10	0.869	15
Hunan	4	9	41.379	11	63.043	11	0.715	17
Guangdong	18	11	72.414	4	78.378	4	5.14	4
Guangxi	1	8	27.586	25	58	24	0.474	24
Hainan	3	6	24.138	26	56.863	25	0.103	29
Chongqing	8	8	44.828	9	64.444	8	1.835	8
Sichuan	4	8	31.034	21	59.184	21	0.756	16
Guizhou	3	8	31.034	22	59.184	22	0.512	22
Yunnan	1	6	24.138	27	56.863	26	0.326	25
Shanxi	7	7	41.379	12	63.043	12	1.611	10
Gansu	2	10	34.483	17	60.417	17	0.715	18
Qinghai	3	7	24.138	28	56.863	27	0.616	20
Ningxia	9	8	34.483	18	60.417	18	1.459	11
Xinjiang	1	6	20.69	30	55.769	29	0.085	30
Mean value	7.667	7.667	41.609		63.982		2.102	

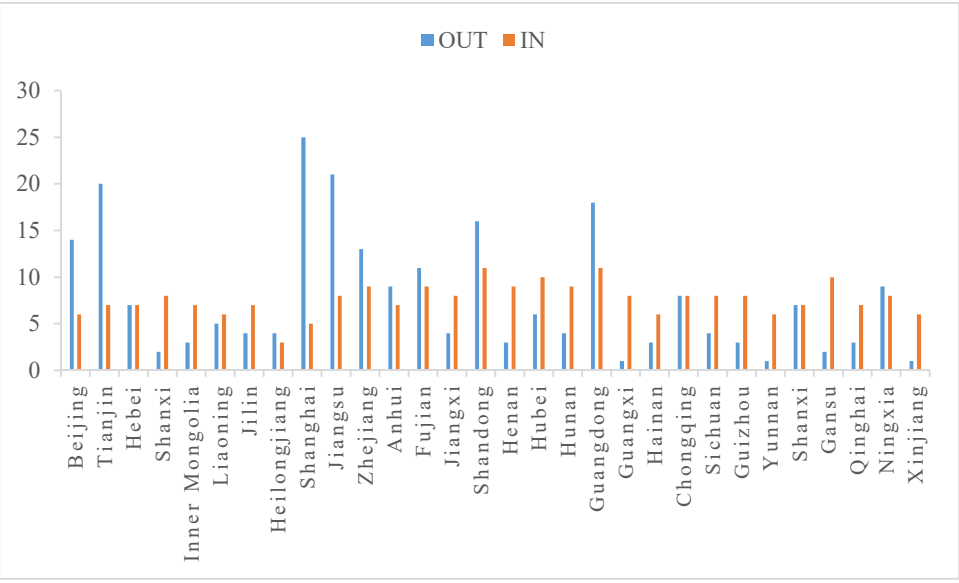

Figure 4. Spatial Spillover Acceptance Relation of China's Regional Ecological Efficiency.

Closeness Centrality

Based on the measurement results of closeness centrality in Figure 3, the mean value of closeness centrality of 30 provinces nationwide is 63.982. There are eight provinces with a closeness centrality value that is higher the mean value: Shanghai, Jiangsu, Tianjin, Guangdong, Shandong, Beijing, Zhejiang, and Chongqing in a sequence from the highest value to the lowest value. A relatively higher closeness centrality shows that these provinces are capable of more quickly developing an internal connection with other provinces in the spatial correlation network of ecological efficiency through the "leading" function in the network, and playing the role of being central actors. The reason for this is that the aforementioned provinces are mainly located in the southeastern coastal areas and have relatively close contacts with inland areas for the purposes of economy and trade. Therefore, these provinces have higher correlation efficiency with other provinces; in addition, they have a relatively strong promotion capacity of ecological efficiency. The closeness centrality of Shanghai among the aforementioned provinces is 90.625, which is far higher than that of other provinces. This shows that other provinces are "closest" to Shanghai in the spatial correlation network of ecological efficiency spillover, while Shanghai is the center of this correlation network. The provinces with the five lowest positions in closeness centrality include Heilongjiang, Inner Mongolia, Xinjiang, Hainan, and Yunnan. All of these provinces are limited by their economic development levels and geographical location, which is why they have relatively lower ecological efficiency levels. Thus it is difficult for them to have spillover effects as they are located at the edges of the spatial network of China's regional ecological efficiency.

Betweenness Centrality

Based on the measurement result of betweenness centrality in the Table 1, the mean value of betweenness centrality of the 30 analyzed provinces nationwide is 2.102. Provinces with a betweenness centrality higher than the mean value include Shanghai, Tianjin, Jiangsu, Guangdong, Shandong, Beijing, and Zhejiang. These provinces have a relatively strong ability to control spillover communications with other provinces in the correlation network of regional ecological efficiency spillover. Notably, the betweenness centrality value for Shanghai is 13.064, which is far higher than that of other provinces. This shows that Shanghai as an international metropolis enjoys the core position in the spatial correlation network of regional ecological efficiency spillover and plays the roles of being an "intermediary agent" and a "bridge". As the central position of Shanghai in nationwide resource trades, logistics shipping, and energy technology are further strengthened, its functions of control and governance are also increasingly strengthened. In addition, the total amount of betweenness centrality of the spatial network of China's regional ecological efficiency is 63.055, and the total sum of betweenness centrality of the seven highest ranking provinces accounts for over 70% of the total amount. These provinces are mainly located in the developed eastern areas which experience relatively quick economic development, while the betweenness centrality of provinces for the five lowest ranking positions is less than 0.3, only accounting for 1.4% of the total amount. These provinces are Xinjiang, Hainan, Heilongjiang, Jiangxi, and Shanxi. The five lowest ranking provinces have relatively slow economic development and remote geographical locations, and some of these locations have relatively serious environmental pollution and low ecological efficiency. Thus, it is difficult for them to control or influence other provinces in the network. The betweenness centrality of various provinces in the correlation network of regional ecological spillover has many irregularities due to its unbalanced feature, and many connections were found to be completed through provinces with more developed economies including Shanghai, Jiangsu, Tianjin, and Guangdong.

4.2.3. Block Model Analysis

The Block model is main way to conduct spatial cluster analysis on a social network. Through block model analysis, the positions and functions of internal structural status and various nodes

(provinces) of a spatial correlation network of ecological efficiency spillover are revealed and depicted. Thus in-depth analysis on correlations among all blocks can be conducted. While referring to the research conducted by Liu Huajun, et al., in this paper, the blocks in the spatial correlation network of regional ecological efficiency spillover are divided into four types. The first one is the net spillover block, where the correlations sent out by that block to other blocks are larger than the spillover correlations received from other blocks; the second one is the bilateral spillover block, where members of that block will send out and receive equal correlations from other blocks, while there are more contacts coming from internal members of that block; the third one is the net benefited block, where members of that block not only receive spillover correlations from members of other blocks, but also receive spillover of internal correlations of that block, while correlations received from other blocks are larger than the spillover correlations sent out by that block to other blocks; the fourth one is the broker block, which has contacts externally, and receives spillover from other blocks. In addition, for the broker block, contacts between that block and members of other external blocks are greater than the contacts between internal members of the block.

In this paper, the CONCOR module of Ucinet is used, the maximum segmentation depth is selected as being 2, and the centralized standard is 0.2. A total of 30 provinces nationwide were divided into four blocks (as seen in Table 5). There are six members in Block I,: Beijing, Tianjin, Hebei, Inner Mongolia, Jilin, and Liaoning, which mainly are provinces of the Circum-Bohai Sea Region; there are six members in Block II: Zhejiang, Fujian, Shandong, Shanghai, Jiangsu, and Guangdong, which mainly are provinces of the eastern areas of the Yangtze River Delta and Pearl River Delta; there are 11 members in Block III: Heilongjiang, Ningxia, Henan, Guizhou, Shanxi, Guangxi, Jiangxi, Yunnan, Gansu, Qinghai, and Xinjiang, which mainly are provinces in the western area; there are seven members in Block IV: Sichuan, Hubei, Shaanxi, Anhui, Chongqing, Hunan, and Hainan, which mainly are provinces in the central area.

In the spatial correlation network of China's regional ecological efficiency spillover, there are 44 spatial correlations within all of the blocks, accounting for 19% of the total number of relations. There are 186 spatial correlations involving blocks engaging with other blocks, accounting for 81% of the total number of correlations. This shows that the regional ecological efficiency spillover effect is dominated by inter-regional spillover rather than intra-regional spillover. The total number of internal relations for the first block is 5, the total number of spillover correlations this block receives from other blocks is 68, and the total number of spillover correlations it has towards other blocks is 42. The desired internal ratio relation figure is 17%, which is larger than the actual internal proportional relation, 7%, which belongs to the "bilateral spillover block". Members of a block will not only trigger a spillover, but also accept spillovers from other blocks; the total number of internal relations for the second block is 21, the total number of spillover correlations it receives from other blocks reaches 28, and the total number of spillover correlations it has to other blocks is 72. The desired internal ratio relation for this block is 17%, which is less than the actual internal proportional relation, 22%, belonging to this "net spillover block". Members of this block are mainly located in eastern areas with higher regional ecological efficiency, which has a significant spatial spillover effect on other regions. The total number of internal relations of the third block is 11, the total number of spillover correlations it receives from other blocks is 72, and the total number of spillover correlations it has to other blocks is 26. The desired internal ratio relation for this block is 34%, which is larger than the actual internal proportional relation, 19%, which shows that it is a "net earnings block". Members of the block are mainly located in western areas with relatively low economic development levels and lower technical levels, and these members predominately accept ecological efficiency spillover from areas with more developed economies and more advanced technology. The total number of internal relations for the fourth block is 7, the total number of spillover correlations it receives from other blocks is 44, and the total number of spillover correlations it has to other blocks is 20. The desired internal ratio relation for this block is 20%, which is greater than the actual internal proportional relation, 26%, making it a "broker block". It therefore functions as a link in the spatial network of regional ecological spillover.

Table 5. Spillover Effect of the Spatially Correlated Blocks of Regional Ecological Efficiency Spillover.

Blocks	Total Number of Received Relation Signals		Total Number of Relation Signals Sent Out		Desired Internal Relation Ratio (%)	Actual Internal Relation Ratio (%)
	Within the Block	Outside the Block	Within the Block	Outside the Block		
Block I	5	42	5	68	17	7
Block II	21	28	21	72	17	22
Block III	11	72	11	26	34	29
Block IV	7	44	7	20	20	26

In order to further investigate the spatial correlation relation among regional ecological efficiency spillover blocks as well as the roles of various blocks in the overall network space, the spatial correlation network density (0.2644) of China's regional ecological efficiency spillover which was measured in the preceding part of the text was then used to transfer the network density matrix of all blocks into an image matrix. The network density of any one block is greater than 0.2644, meaning the network density of each one of the blocks is greater than their overall network density. If the ecological efficiency spillover is more highly concentrated internally within a block, then the assignment is 1, conversely, the assignment is 0, as shown in Table 6. There are high correlations of regional ecological efficiency spillover internally within both Block I and Block II, while they also accept spillover correlations from Block III and Block IV. This shows that Beijing-Tianjin-Hebei, the Yangtze River Delta region, and the Pearl River Delta Region with high economic development levels and advanced technology play the role of an "engine" in promoting China's overall regional ecological efficiency. Meanwhile, Block III and Block V, which cover the central and western regions with relatively low economic development and backward technology, are the acceptors of regional ecological efficiency spillover from other regions. In addition, the phenomenon of spillover of Block V to Block III shows that various blocks give rise to comparative advantages in the spatial correlation network of regional ecological efficiency spillover with an increasingly obvious overall linkage effect.

Table 6. Density Matrix and Image Matrix of Spatially Correlated Blocks of Regional Ecological Efficiency.

Block	Density Matrix				Image Matrix			
	Block I	Block II	Block III	Block IV	Block I	Block II	Block III	Block IV
Block I	0.167	0.472	0.53	0.381	0	1	1	1
Block II	0.494	0.7	0.309	0.476	1	1	1	1
Block III	0.152	0.121	0.1	0.104	0	0	0	0
Block IV	0.267	0.071	0.23	0.167	1	0	1	0

5. Analysis on the Influential Factors of a Spatial Correlation Network of Regional Ecological Efficiency

5.1. QAP Correlation Analysis

Based on our the analysis on the influential factors of a spatial network of regional ecological efficiency spillover, the paper builds the mode of influential factors of the spatial network which is as follows:

$$D = f(X_1, X_2) = f(GP, EL, IS, FDI, ER, TI). \quad (5)$$

In the formula, it is explained that the variable D is the two-value network matrix of the correlation relation of regional ecological efficiency spillover determined in the preceding part of the text; EL is the difference matrix of the economic development level; IS is the difference matrix of industrial structure; FDI is the difference matrix of freedom degree of investment; ER is the difference matrix of environmental regulation intensity; TI is the difference matrix of technical improvement. In addition to

D, the rest of index data was constituted by an absolute difference of mean values for all of the analyzed provinces. On the basis of this, the "relational data" adopted in the paper can explain the relatively high similarity among variables. In order to avoid measuring errors caused by multicollinearity, the of Quadrati Assignment Procedure (QAP) method was adopted in this paper to conduct empirical analysis on the influential factors of the spatial correlation network of China's regional ecological efficiency spillover [58].

Results of the QAP correlation analysis on the difference matrix of the spatial spillover of China's regional ecological efficiency and influential factors are reported in Table 7. It was found that the economic development level passed the 1% significance level test, and the correlation coefficient was 0.148. This shows that the economic development level has a very significant positive effect on the spatial spillover of regional ecological efficiency, The correlation coefficients of industrial structure, freedom degree of investment and technical improvement as the measurement indexes of regional difference with a spatial spillover of regional ecological efficiency respectively are 0.121, 0.068, and 0.112, and these results all pass the 5% significance level test. This shows that industrial structure, freedom degree of investment, and technical improvement have significant positive effects on the spatial spillover of regional ecological efficiency. The correlation coefficient of environmental regulation with a spatial spillover of regional ecological efficiency is −0.08 and passes the 5% significance level test. This shows that environmental regulation has a significant negative effect on the spatial spillover of regional ecological efficiency. In the paper, the probable reason for this may be that enterprises with relatively serious pollution often transfer some of this pollution to provinces with a lower intensity of environmental regulation. This contributes to high levels of pollution in these provinces. The correlation coefficient between the spatial spillover of regional ecological efficiency and the spatial proximal matrix is 0.17, and passes the 1% significance level test. This shows that the proximal nature of geographical location among all provinces has a very significant positive influence on the spatial spillover of regional ecological efficiency.

Table 7. Correlation Analysis on Influential Factors of the Correlation relation of China's Regional Ecological Efficiency Spillover.

Variable	Correlation Coefficient	Significance Level	Mean Value of Coefficient	Standard Difference
GP	0.170	0.000 ***	−0.000	0.038
EL	0.148	0.000 ***	−0.000	0.041
IS	0.121	0.035 **	0.001	0.062
FDI	0.068	0.044 **	0.000	0.038
ER	−0.080	0.024 **	0.000	0.039
TI	0.112	0.039 **	0.001	0.058
	Minimum	Maximum	P ≥ 0	P ≤ 0
GP	−0.136	0.148	0.000	1.000
EL	−0.156	0.143	0.000	1.000
IS	−0.174	0.237	0.035	0.971
FDI	−0.160	0.153	0.044	0.968
ER	−0.165	0.144	0.982	0.024
TI	−0.155	0.243	0.039	0.968

Note: *** and ** respectively represent the significance of coefficients at the significance levels of 1% and 5%.

5.2. QAP Regression Analysis

For this paper, 5000 random permutations were selected, and the adjusted coefficient of determination obtained was 8.4%. This shows that these variables can explain 8.4% of the spatial correlation of regional ecological efficiency spillover. Also, the probability value of adjusted coefficient of determination was 0, which shows that the probability of the coefficient of determination being

generated for random permutations was no less than the actually observed coefficient of determination, which was the probability value of the one-tailed test. This shows that the adjusted coefficient of determination passes the 1% significance level. Table 8 shows the regression coefficient and test indexes of the regional difference matrix and geographical adjacency obtained by the QAP regression analysis. For these results, $P \geq 0$ expresses the probability of a regression coefficient after random permutation being no less than the actually observed regression coefficient; $P \leq 0$ is the probability of the regression coefficient after a random number of permutations being no more than the actually observed regression coefficient. The regression coefficient of regional difference and ecological efficiency spatial spillover of industrial structure, environmental regulation, economic development, and technical improvement respectively were 0.08, −0.05, and 0.109, meaning industrial structure and environmental regulation passes the 10% significance test, while economic development passes the 1% significance test. This shows that the regional differences of industrial structure and economic development are proxy variables for regional difference; the larger the differences between them are, the more likely that there will be the spatial spillover of regional ecological efficiency, while regional industries and environmental regulation have a negative influence on the spatial spillover of regional ecological efficiency. The reason for this may be that as pollution charges and investments in pollution control increase, highly polluting enterprises seek to shift to provinces in China's central and western areas with relatively low environmental regulation, leading to more serious environmental pollution in these areas. Regional differences over economic development and technical improvement as well as ecological efficiency spatial spillover do not pass the significance test. This shows that regional differences cannot significantly affect the formation of the correlation network of China's regional ecological efficiency spillover. The reason for this may be that, under the guidance of the external policy of China, its FDI mainly focuses on the coastal areas, while multi-national; enterprises transfer their high pollution and energy consumption in the industrial chain to developing countries such as China, causing a large amount of pollutants to be discharged in these countries. The "sanctuary effect of pollution" has been verified, while technical improvement to alleviate this effect requires a lot of investment. High polluting enterprises attempt to reduce their costs by improving their profits; however, this also causes more serious environmental pollution. Existing technical barriers also affect the formation of the correlation relation of China's regional ecological efficiency spillover. The regression coefficient of spatial adjacency matrix is 0.242, passing the 1% significance level test. This shows that the geographical proximity effect has a significant positive effect on the spatial spillover of environmental pollution.

Table 8. Quadratic Assignment Procedure (QAP) Regression Analysis on Spatial Correlation Relationship of China's Regional Ecological Efficiency Spillover.

Variable	Non-Standardized Regression Coefficient	Standardized Regression Coefficient	Significance Level	P ≥ 0	P ≤ 0
IS	0.079890	0.081583	0.067 *	0.067	0.934
ER	−0.050231	−0.055692	0.067 *	0.934	0.067
GP	0.241681	0.195996	0.000 ***	0.000	1.000
EL	0.109605	0.123446	0.004 ***	0.004	0.997
FDI	0.018659	0.020838	0.288	0.288	0.712
TI	0.043734	0.045495	0.177	0.177	0.823

Note: *** and * respectively represent the significance of coefficients on the significance levels of 1%, and 10%.

6. Conclusions

Based on the scientific measurement of China's regional ecological efficiency, the spatial correlation relation of China's regional ecological efficiency spillover can be determined by using VAR Granger causality test model, In this context, we built a spatial weight matrix, then revealed the spatial correlation network structural features of China's regional ecological spillover using social network

analysis, and then conducted an empirical survey on influential factors. Thus, the following conclusions were obtained:

(1) The ecological efficiency of most provinces in China has clearly been inefficient for a long time. The spatial correlation relationship of regional ecological efficiency spillover in China however presents a more complex network structure. All of the studied provinces are in the spatial network, and the network at large has strong stability. There are possibilities for all of these provinces to have reciprocal ecological efficiency spillover relationships with other provinces. Shanghai, Jiangsu, Tianjin, Guangdong, Shandong, Beijing, Zhejiang, Fujian, and Chongqing have the leading positions in the network and play the "engine" role in the optimization of nationwide regional ecological efficiency, which is the main driving force improving the level of regional ecological efficiency spillover in China; Hainan, Yunnan, Qinghai, Heilongjiang, and Xinjiang are at different edges of the network.

(2) Block model analysis shows that six provinces (which include the city of Shanghai) belong to the "net spillover block", which are in the core positions of the network and play a "guiding" role; six other provinces (which include the city of Beijing) belong to the "bilateral spillover block", which are in the central positions of the network and play a bilateral "guiding" role both internally and outside their own block; seven provinces, including Anhui, belong to the "broker block", which are in key positions of the network and play a "bridge" intermediary role; 11 provinces, including Guangxi, belong to the "net benefited block", which are in edge positions of the network and play an "acceptor" role.

(3) Results of the QAP correlation analysis show that influential factors of regional differences including the economic development level, industrial structure, freedom degree of investment, and technical improvement have a significant positive correlation relationship with the spatial correlation network structure of China's regional ecological efficiency spillover while the environmental regulation difference has a significant negative correlation; geographic proximity also has a significant impact on the spatial correlation of regional ecological efficiency spillover. Results of the QAP regression analysis show that regional differences involving industrial structure, economic development, and technical improvement have a positive influence on the spatial spillover of ecological efficiency, while environmental regulation have a negative influence; regional differences of economic development and technical improvement do not pass the significance test, showing that regional differences cannot significantly affect the formation of the correlation network of China's regional ecological efficiency spillover; in addition, geographical proximity has a significant positive influence on the spatial spillover of environmental pollution.

Based on the above analysis and research findings, the insights of this research are as follows:

(1) Governments at all levels in China must embed the spatial spillover network of regional ecological efficiency in their regional coordinated development systems. Not only should they pay close attention to "attribute dates", but they must also attach importance to the level of "relational data" available. They must continuously innovate through the use of coordinated development, promote the balanced development of economic development and the ecological environment from "local" to "overall" as well as from "point" to "plane", increase the use of effective ways of boosting the spatial correlation of regional ecological efficiency spillover, continuously optimize the spatial correlation network structure of regional ecological efficiency spillover in China, accelerate the formation of this spatial correlation network, and gradually form a "quantity-structure" driven cross-region coordinated promotion mechanism. For the latter proposal, Chinese governments should promote support by high-efficiency provinces of low-efficiency provinces and speed up the flow of knowledge, talent, and other resources between provinces through the use of "nonhierarchical" network structure features, so that the regional ecological efficiency spillover network has a linkage and coordination effect in the transmission process.

(2) It is important to fully understand the blocks' characteristics affecting the spatial correlation network structure of regional ecological efficiency spillover in China as well as the position and role of each region in the network. Based on the principles of focused and meticulous regulation and the characteristics of social and economic development of different blocks, leaders should formulate

differentiated strategies to improve regional ecological efficiency. For every domain where policies benefit regional ecological efficiency spillover, policymakers should find out who is the "leader" within each block that encourages it to play its spillover role, and then proceed towards the sound and rapid development of "point to block" spillovers within the block, as well as encouraging the promotion of the whole network's further development.

(3) Policymakers should comprehensively consider the influencing factors of the spatial correlation network of regional ecological efficiency spillover in China, improve the interregional element flow mechanism once it has been developed, and give full play to the diffusion effect of element flow. Policymakers and leaders should facilitate the maximum level of cooperation between the market and governments to help achieve these goals, which means not only making use of the mechanisms of price, supply and demand, and market competition to enable the market to play a decisive role, strengthen the interaction between core regions and marginal regions, and promote the improvement of the ecological efficiency of the marginal regions, but also make use of economic, legal, and administrative means for government to improve the regional ecological efficiency of marginalized provinces on the edge of the network, in order to reduce spatial imbalance of regional ecological efficiency in China.

At the same time, there are some deficiencies in this study. The geographical unit of the regional ecological efficiency measurement is relatively large. There are also major differences in the ecological environment endowment and both main functions and positions of different cities in the various provinces, which made it difficult to evaluate the differences among different cities in a province at the provincial level. Therefore, evaluation at the city level is the most promising direction for future research.

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