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Economic Dependence Relationship and the Coordinated & Sustainable Development among the Provinces in the Yellow River Economic Belt of China

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Abstract: This study uses the mutual information method to study economic dependence among the provinces in the Yellow River Economic Belt, constructs the core dependence structure through the maximum spanning tree method, and uses the rolling window method to observe the changes in the dependence structure from a dynamic point of view. It has been found that there are extensive economic links among the nine provinces in the Yellow River Economic Belt, but that the degree of economic dependence varies greatly in different time periods. When economic development and the capital market are overheated, the interregional dependence is stronger, while the dependence decreases when economic development is in a state of contraction or when the total demand is relatively reduced. In addition, the phenomenon of geographical clustering of economic dependence is not obvious among provinces in the Yellow River Economic Belt. Most of the provinces maintain strong economic dependence with the economically developed provinces, and the economically developed provinces also maintain strong economic ties with one another. Finally, the implementation of the Yellow River Economic Belt strategy strengthens the economic links between the less developed provinces and the other provinces in the region, and promotes coordinated and sustainable development in the region.

Keywords: economic dependence; regional coordinated and sustainable development; mutual information; Yellow River Economic Belt

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1. Introduction

At present, with the deepening of economic globalization and trade liberalization, economic exchanges, capital flow, and population flow among different countries and regions around the world are becoming more frequent and convenient. Even though there are signs of trade protectionism in some countries at present, the degree of economic dependence among various economies will continue to deepen on the whole. This is because extensive economic dependence can make the allocation of capital, production resources, and labor more reasonable and efficient [1]. The current research on regional links is mainly divided into the following three aspects: The first is from the perspective of infrastructure networks; this is mainly divided into the transportation infrastructure and communication infrastructure networks. Through the close connection of infrastructure networks, the relationships between various regions are strengthened [2,3]. The second aspect of research is from the perspective of enterprise organization—for instance, multinational enterprises, headquarters and branches, enterprise ownership, changes in industrial spatial network structures, etc.,—to investigate the resulting changes in regional economic relationships [4–7]. The third aspect is from the perspective of population flow, capital flow, and information communication, to study whether these flows will bring changes in the degree of interregional economic dependence [8–12]. While interregional economic dependence relationships are mainly manifested in the interactions between economic entities within the region(s) [13], the school of relational geography further points out that the study

of economic geography should focus on the impact of the interactions between regional economic entities on regional economic development [14].

With the extensive deployment of capital, production resources, labor, etc., interregional economic dependence has been strengthened, and the urbanization process and the formation of large urban agglomerations will also have a positive effect on the efficient economic development of the region(s) [15]. At present, some urban agglomerations have been formed or are being constructed around the world, such as the Northeast Atlantic coastal urban agglomerations in the United States, the Pacific coastal urban agglomerations in Japan, and the British urban agglomerations in the United Kingdom. After more than 40 years of reform and opening-up, China's urbanization level and degree of economic development have been greatly improved. In order to adapt to the new development mode of the region, China's urban agglomerations must be developed. In order to meet the needs of urbanization, the Chinese government is now speeding up the construction of urban agglomerations and regional development belts. On regional economic dependence and regional economic coordination and sustainable development, it is pointed out by the Development Research Center of the State Council of China in "China's Regional Coordinated Development Strategy" that the coordinated development of regional economy includes several aspects; the main points are increasing the economic driving effect of rich areas on the less developed regions, and promoting regional integration. From the above understanding of the coordinated development of regional economies, it can be seen that the coordinated development of regional economies should include interaction between regions and coordinated development among various economic units, and the existing literature finds that close regional economic dependence will affect the sustainable development levels of each city [16].

With the deepening construction of urban agglomerations and regional economic development belts, the coordinated development of various regions has been widely considered. Studies have shown that efficient and coordinated industrial and economic layouts will promote regional development [17]. Furthermore, in terms of the regional coordinated development of urban agglomerations, existing studies have conducted extensive research on the following aspects: the degree of regional coordinated development [18–20]; the influencing factors in the development process of urban agglomerations, and the relevant definitions of urban agglomerations [21–27]; and the formation and development mechanisms of regional dependent structures [28–32].

In recent years, the Chinese government has proposed focusing on building important economic belts and development poles in the Yangtze River Basin, the Yellow River Basin, and the coastal areas, in order to increase economic ties and cooperation between provinces and cities in the above areas, and form a new and more dynamic regional development pattern. Under this background, the Yellow River Basin High-Quality Development Economic Belt, with ecological protection and sustainable regional development, has emerged. This paper takes the nine provinces in the Yellow River Basin as the study object, calculates the degree of economic dependence among the above provinces in this region, constructs the core structure of the economic links, and compares their changes in the past six years. Most importantly, the relevant conclusions of this study provide some important reference directions for the coordinated and sustainable development of the Yellow River Economic Belt in the future, which is more conducive to promoting coordination and cooperation among the provinces in this region. At present, the research on China's regional economic dependence and regional coordination and sustainable development initiatives mainly focuses on the Yangtze River Economic Belt. It has been found that there is a high correlation between the strength of economic connection and sustainable development in the Yangtze River Economic Belt [33]. Zheng and Xiang found that the degree of economic dependence and the level of economic growth showed the same trend; that is, the less a region is connected with others, the lower its level of economic growth. Based on the 11 provinces in China's Yangtze River Economic Belt, they found that Guizhou and Yunnan, which are the most underdeveloped provinces of the west, are highly dependent on the economic

development of the more developed provinces. Their results show that the development of economic integration can rapidly promote the economic growth of underdeveloped areas, and that regional integration is an important way to break through the unbalanced development [34]. However, due to the relatively recent establishment of the Yellow River Economic Belt, there are few studies on economic interdependence among the provinces in this region. Therefore, this paper takes the Yellow River Economic Belt as the analysis background in order to study interdependence among the provinces in the region.

Mutual information is a kind of relative entropy, which measures the interdependence of two variables by the information they share. Mutual information can measure not only the linear dependence but also the nonlinear dependence between variables; at the same time, the mutual information method is data-driven, does not rely on specific models, and has a wide range of applicability [35,36]. At present, the theory and method of mutual information has been widely used in the study of economic dependence; for example, Kharrazi et al. used mutual information to build a global oil trade network from 1998 to 2012, and found that mutual information can help researchers track the changes in dependence between trading partners, and provide references for policy evaluation [37]. Wang X.D. et al. used mutual information to study the financial contagion effect of the major global stock markets during the 2008 financial crisis, and found that mutual information can effectively investigate the interdependence of, and changes to, various stock markets during different periods of the financial crisis [38]. Wu X.B. et al. used mutual information and other methods to study the regional dependence of China's stock market, and constructed the regional dependence network of the stock market [39]. Mohti et al. used mutual information and DFA methods to study the nonlinear dependence and efficiency of stock markets [40]. Viegas et al. used mutual information and other methods to quantify the distance between the economic system, such as business, and the effective market allocation of Japan, so as to study the efficiency level of economic activities in the region [41]. Through the above research, it can be seen that mutual information is an effective method for studying economic dependence and building the dependence network, but the application of mutual information theory is relatively less applicable to the economic interdependence of regions and sub-regional provinces.

This article examines the economic interdependence of nine provinces in the Yellow River Economic Belt over the past six years, as well as the core structure and dynamic changes of their interdependence, and through the comparison of the average interdependence of the provinces over the past six years, the sustainable development of the Yellow River Economic Belt is investigated. We mainly consider the following issues:

(1) Analysis of the economic interdependence of the nine provinces in the Yellow River Economic Belt over the past six years.
(2) The core structure of, and dynamic changes to, economic interdependence among the nine provinces of the Yellow River Economic Belt over the past six years.
(3) Whether the development strategy of the Yellow River Economic Belt will contribute to the sustainable development of the region's economy.

The rest of this paper is organized as follows: Section 2 introduces the methods. Section 3 introduces the data used in this study. Section 4 displays the empirical results and some analyses. Section 5 displays the conclusion of this paper. The research methodology infographic of this study is shown in Figure 1.

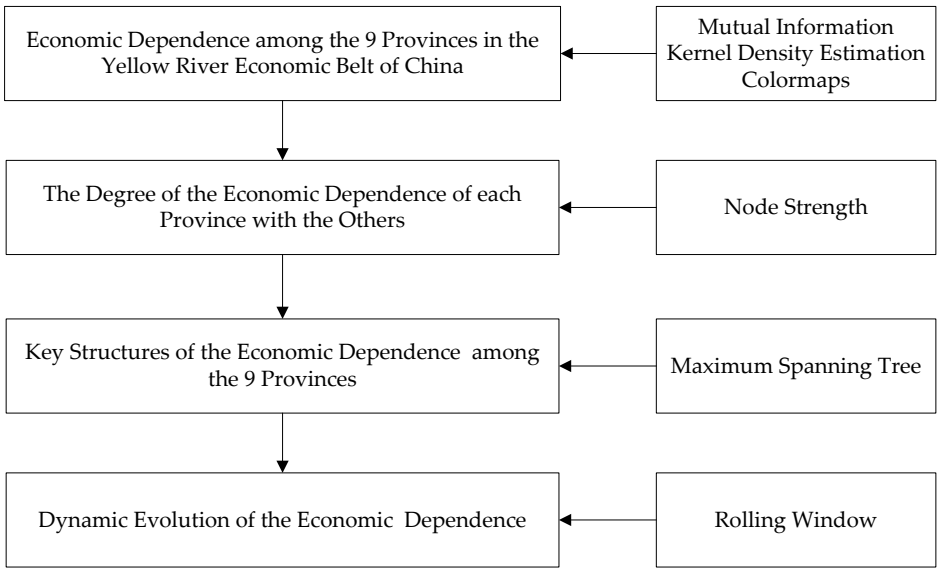


Figure 1. Research methodology infographic.

2. Methods

In this study, mutual information and kernel density estimation are used to calculate the economic interdependence of provinces in the Yellow River Economic Belt. In previous studies on the coordinated development and economic dependence of urban agglomerations, methods such as spatial econometric modelling, regional dependence structure, and network risk propagation were applied to describe the dependence of each node in urban agglomerations or urban development clusters [42–45]. Compared with the above methods, mutual information and kernel density estimation have the following advantages: First of all, the traditional econometric-model-based study of regional economic interdependence is mainly applied in the linear condition, but some studies have proved that the economic time series often show nonlinear characteristics, and mutual information can be used to calculate the interdependence of variables under both linear and nonlinear conditions [46–50]. In addition, the econometric models calculating the dependence relationship often need to set the parameters of the model in advance, and the setting of parameters will affect the final estimation results, while mutual information is model-free, therefore it is not necessary to set the model in advance. Finally, a large number of studies need to make assumptions about the distribution of samples. For example, in most cases, it is assumed that the samples obey normal distribution, but in reality, the samples tend to show peaked and thick-tailed distribution. Therefore, this paper uses the kernel density estimation method to calculate the mutual information between variables, which does not depend on specific assumptions of data distribution.

2.1. Mutual Information

The definition of information entropy was established by Shannon in 1940s, and it has been considered that information entropy can be used to measure the uncertainty of an event. According to the definition given by Shannon, the entropy of a discrete random variable X can be expressed as:

$$H(X) = -\sum_{x \in \chi} p(x) \log p(x) \quad (1)$$

where χ is the set of all states of the random variable X, $p(x)$ is the probability of x, and the base of the logarithm is commonly chosen as 2; the unit is the bit.

For the two random variables X and Y, the joint entropy between the two variables could be defined as:

$$H(X,Y) = -\sum_{x\in X}\sum_{y\in Y} p(x,y)\log p(x,y) \tag{2}$$

where $p(x,y)$ is the joint probability of x and y.

The definition of MI between X and Y is given in Formula (3) [51]:

$$MI(X,Y) = \sum_{x\in X}\sum_{y\in Y} p(x,y)\log\frac{p(x,y)}{p(x)p(y)} \tag{3}$$

According to Formulas (1) and (2), MI could be rewritten as Formula (4) [52]:

$$MI(X,Y) = H(X) + H(Y) - H(X,Y) \tag{4}$$

MI measures the information that one variable discloses about another [53]. It can be seen from Formula (4) that, in a mathematical sense, the mutual information value of two variables can be expressed as the sum of the entropy of the two variables and the difference between the joint entropy of the two variables. Theoretically speaking, the mutual information of two variables represents, when the information contained in one of the two variables is fully known, the degree by which the known information of known variable reduces the uncertainty of the other variable; alternatively, it can be understood as the degree by which the known information of one variable increases the information of the other variable. The mutual information between two variables can be understood as the amount of information shared by two variables; that is, if one of the two variables is known, and the uncertainty of the other variable can be greatly reduced as a result, then it can be considered that the known variable contains a lot of information about the other variable.

2.2. Kernel Density Estimation

Let $U = \{u_1, u_2, \ldots, u_N\}$ be a d-dimensional real variable, and the kernel density of its probability density function is estimated by Formula (5):

$$\hat{f}(u_j) = \frac{1}{Nh^d}\sum_{i=1}^{n} K\left(\frac{u_j - u_i}{h}\right) \tag{5}$$

where h is the window parameter, also known as bandwidth, and $K(\cdot)$ is the d-dimensional kernel function. Then, under the Gaussian kernel function, Formula (5) is transformed into (6):

$$\hat{p}(\boldsymbol{u}_j) = \frac{1}{Nh^d}\sum_{i=1}^{n}\frac{1}{\sqrt{(2\pi)^d|S|}}\exp\left(-\frac{(\boldsymbol{u}_j - \boldsymbol{u}_i)^T S^{-1}(\boldsymbol{u}_j - \boldsymbol{u}_i)}{2h^2}\right) \tag{6}$$

where S is the determinant of its covariance matrix.

The choice of bandwidth has a great influence on the estimation effect. According to the authors of [41], this paper selects the optimal bandwidth, as shown in Formula (7):

$$h = \left(\frac{4}{d+2}\right)^{1/(d+4)} N^{-1/(d+4)} \tag{7}$$

The probability density of samples can be obtained by kernel density estimation, and then the entropy formula can be obtained as follows:

$$H(\boldsymbol{U}) = -\frac{1}{N}\sum_{t=1}^{N}\log\hat{p}(\boldsymbol{u}_t) \tag{8}$$

Combined with Formulas (4) and (8), we can obtain the final formula with which to calculate the mutual information value of the two variables, as shown in Formula (9):

$$I(X,Y) = -\frac{1}{N}\sum_{t=1}^{N}\log\hat{p}(x_t) - \frac{1}{N}\sum_{t=1}^{N}\log\hat{p}(y_t) + \frac{1}{N}\sum_{t=1}^{N}\log\hat{p}(x_t,y_t) \quad (9)$$

The basis and premise of empirical research is to estimate the probability density and distribution of the observed samples. At present, a large number of studies are based on assumptions, such as the assumption that the observed samples will obey normal distribution. Under this assumption, the parameters in the samples are estimated. However, a large number of economic time series are not strictly subject to a single probability distribution, so the previous assumption that the samples will obey a certain distribution will lead to inaccurate parameter estimation, which will in turn lead to bias in the results. In order to overcome this problem, this paper uses the kernel density estimation method, which is a nonparametric estimation method.

3. Data

This paper selects China's regional stock price index as the research object, which reflects the overall performance of listed companies in different regions of China's A-share market, depicts the development characteristics of regional economies, and is an important indicator by which to measure the development of regions. In China, the listed companies in a region often reflect the main economic development characteristics and industrial structure of a province or a city, and they can reflect not only the economic and capital development level and potential, but also the business environment, policy support, and infrastructure construction—which may be called "soft power"—in one region. In addition, it has been proven by research that regional economic interconnection manifests as the interaction between regional economic entities—which may take the form of business connection, capital circulation, etc., [13]—and the daily trading data of China's regional stock price index can reflect the economic development of one region [39].

Although there are many factors affecting stock prices and the co-variation among them, this paper does not use a single stock price dataset, but rather a comprehensive index, which can reflect regional development after calculation and adjustment. In addition, this paper calculates the dependence relationships among the regional indices in each of the six years from 2015 to 2020, and finds common conclusions, which may also help to avoid inaccuracies in the calculation results caused by changes to the stock market during a certain period. The data selected in this paper come from the Wind Economic Database, and the time range of the data is from 5 January 2015 to 31 December 2020—a total of 6 years of indexed daily closing prices. The numbers and index names are listed in Table 1.

Table 1. The numbers, names and the codes of the nine regional indices.

No.	Index Name	Code	No.	Index Name	Code
1	Gansu Index	CN6004	6	Shandong Index	CN6021
2	Henan Index	CN6010	7	Shanxi Index	CN6022
3	Inner Mongolia Index	CN6018	8	Shaanxi Index	CN6023
4	Ningxia Index	CN6019	9	Sichuan Index	CN6025
5	Qinghai Index	CN6020			

In accordance with previous literature, this paper calculates the logarithmic return of each index according to Formula (10):

$$R(t) = \ln P(t) - \ln P(t-1) \quad (10)$$

where $p(t)$ and $p(t-1)$ are the daily closing prices of the regional index on dates t and $t-1$, respectively, and $R(t)$ is the logarithmic return of the regional index on date t. Table 2 shows

the descriptive statistical results of the logarithmic rate of return of the nine provinces. It can be seen that the time series after the difference are stable, and none of them obey Gaussian distribution.

Table 2. Statistical characteristics of the nine regional indices.

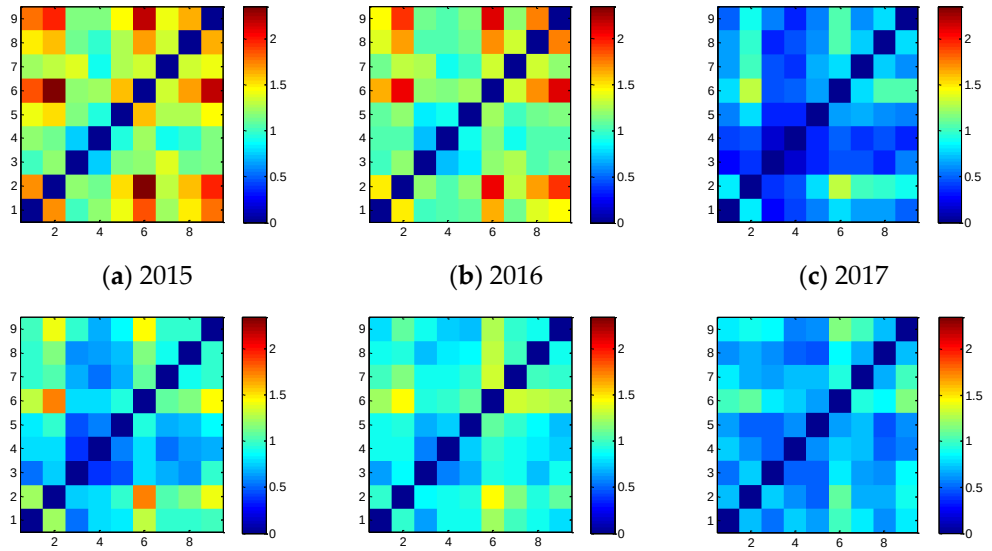
No.	Mean	Std. Dev.	Skewness	Kurtosis	ADF Statistic	Jarque–Bera Statistic
1	-8.31×10^{-5}	0.0198	−1.0759	7.0631	−34.4492 ***	1286.827 ***
2	3.33×10^{-4}	0.0179	−1.0290	7.3840	−35.6237 ***	1427.818 ***
3	3.18×10^{-4}	0.0178	−0.7248	6.8397	−37.6013 ***	1025.385 ***
4	-1.82×10^{-4}	0.0187	−0.8611	6.2893	−34.2632 ***	839.1872 ***
5	-2.38×10^{-4}	0.0204	−0.8815	6.5795	−35.6890 ***	969.1649 ***
6	3.25×10^{-4}	0.0176	−1.0764	7.7921	−35.3815 ***	1680.070 ***
7	4.91×10^{-6}	0.0186	−1.1569	9.0852	−35.3596 ***	2580.079 ***
8	4.08×10^{-4}	0.0206	−0.7889	6.7558	−34.6022 ***	1010.246 ***
9	5.54×10^{-4}	0.0188	−1.0312	7.3076	−34.4032 ***	1388.468 ***

Note: *** means statistical significance at the 1% level.

4. Empirical Analysis

4.1. Mutual Information among the Regional Indices

Figure 2 shows the mutual information values of the economic interdependence of the nine provinces in each of the past six years. In order to visually observe the changes in economic interdependence in different years, this study uses thermal maps to display the results, in which the abscissa and ordinate represent the numbers of the nine provinces as indexed in Table 1. In order to achieve a better contrast effect, the value ranges of these six thermal maps are all adjusted to 0–2.348, because the maximum mutual information value among provinces over the six years is 2.3472 between Henan (No. 2) and Shandong (No. 6) in 2015.



(**a**) 2015 (**b**) 2016 (**c**) 2017

(**d**) 2018 (**e**) 2019 (**f**) 2020

Figure 2. Colormaps of the MI among the nine provinces in each of the six years.

From Figure 2, it can be observed that economic interdependence exists, but at different strengths in different years. Over the six years from 2015 to 2020, the economic interdependence of the nine provinces in the Yellow River Economic Belt has changed greatly, and this change can be clearly observed in the thermal maps in Figure 2. First of all, in 2015 and 2016, the economic dependence among the nine provinces was strong, with the average MI reaching 1.3830 and 1.2730, respectively—among which Henan (No. 2),

Shandong (No. 6) and Sichuan (No. 9) showed particularly high economic interdependence, especially in 2015, when the interdependence of Henan (No. 2) and Shandong (No. 6) was the largest among all regional indices in all six years. The strong economic interdependence of the provinces in 2015 and 2016 is related to the overheated Chinese economy and the massive bubble in China's capital market at that time. In 2015, China's capital market was highly volatile; as a barometer of the economy, the stock market began to fall off in June that year, and this fluctuation continued until 2016. The overheating of economic development and the capital market naturally increased the exchange of economic activities and the flow of funds, thus intensifying the economic ties between regions. Since then, China has introduced a number of policies and measures to stabilize the economy and the capital market. Therefore, from the thermal maps in Figure 2, it can be seen that the economic interdependence of the nine provinces was greatly reduced in 2017, and from the results in Table 3, we can see that the economic interdependence of the provinces in 2017 was only 0.6204, which is the lowest value among the six years involved in this study, and only half of that in 2016.

Table 3. Average MI in each of the six years.

	2015	2016	2017	2018	2019	2020
Average MI	1.3830	1.2730	0.6204	0.9004	0.9425	0.7209

Table 3 shows the average MI of each year, and these values can be used to compare the overall situation of economic interdependence among the nine provinces over the six years. From the results displayed in Table 3, it can be seen that with the introduction and deepening of the Yellow River Economic Belt strategy, the average interdependence of the provinces in 2018 and 2019 was improved to a certain extent, and the average mutual information value in 2019 was 0.9425, which is 50% higher than that in 2017. Some studies have shown that the economic interdependence of provinces in some regions is closely related to the sustainable development levels of the region in question. The economic interdependence of provinces in the region promotes overall sustainable development level of the region [16,33]. This also shows that the introduction of the Yellow River Economic Belt policy will promote the sustainable development of the economy of the this region. However, in 2020, this value dropped to 0.7209, which is only 76.49% of that in 2019. This was due to the reduction of social demand and the closure of regions caused by COVID-19, which restricted the business activities of entities in different provinces, resulting in a huge reduction in the economic interdependence of the nine provinces.

Based on the above analysis, the following conclusions can be drawn: The economic interdependence of the provinces in the Yellow River Economic Belt changed with their economic development. In overheated stages of economic development—such as in 2015 and 2016—the interdependence was relatively strong, while in shrinking stages of economic development, or in a relatively declining stage of total demand—such as in 2017 and 2020, respectively—the interdependence is relatively weak.

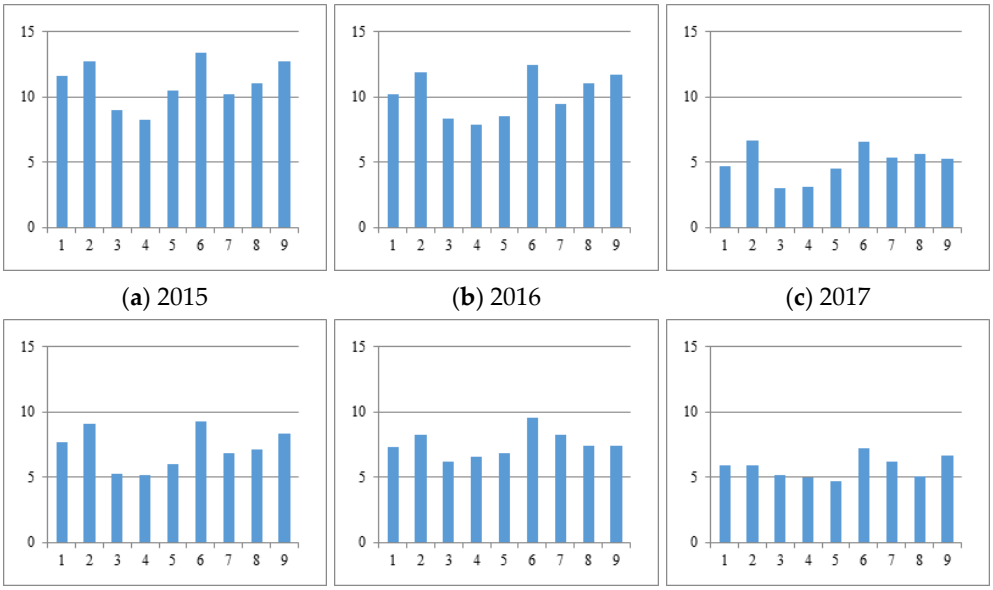
This study then analyzes the strength of each node (NS) of the nine regional indices' dependence networks over the past six years. The node strength reflects the sum of the mutual information values between each regional index and other indices during a certain period, as shown in Formula (11):

$$NS_i = \sum w_{ij} \tag{11}$$

where w_{ij} is the mutual information value between node i and node j.

Figure 3 shows the strength of each node of the nine regional indices' networks at different periods. The abscissa in the figure represents the regional index number in Table 1, while the ordinate represents the strength value of the nodes (NS). Table 4 shows the standard deviation of the regional index node strength of the nine provinces in each

year, which is used to reflect the differences in node strength among provinces in the Yellow River Economic Belt in each year.



(**a**) 2015 (**b**) 2016 (**c**) 2017

(**d**) 2018 (**e**) 2019 (**f**) 2020

Figure 3. The NS value of the nine regional indices in each of the six years.

It can be seen from the results in Figure 3 that the node strength of Inner Mongolia (No. 3), Ningxia (No. 4), and Qinghai (No. 5) is the smallest in almost all of the six years, while the node strength of Henan (No. 2), Shandong (No. 6), and Sichuan (No. 9) is the largest in almost all of the years, which indicates that the interdependence of Inner Mongolia, Ningxia, Qinghai and the other provinces is weak, while the interdependence of Henan, Shandong, Sichuan and the other provinces is strong, which also echoes some of the conclusions from Figure 2. This result is consistent with the conclusion of the authors of [34]; that is, that the level of regional economic development is related to the degree of economic closure of the region. When the economic development of a region is more closed, the level of economic development of the region is worse. In this study, Inner Mongolia (No. 3), Ningxia (No. 4), and Qinghai (No. 5) are located in the western region of China, and their economic development levels are relatively low. Meanwhile, Shandong (No. 6) is the only eastern coastal province in the Yellow River Economic Belt, with strong economic foundations and huge development potential, while Henan (No. 2) and Sichuan (No. 9) are the provinces with the greatest economic potential in the central and western regions of China, respectively. It can be seen that the provinces with better economic development conditions and greater development potential have larger node strength and have stronger economic interdependence with other provinces, while the provinces with poor economic development levels have relatively closed economic development.

Table 4. Standard deviations of the NS in each of the six years.

	2015	**2016**	**2017**	**2018**	**2019**	**2020**
S. D. of NS	1.6554	1.6026	1.2371	1.4366	0.9717	0.8044

In addition, from the results in Table 4, it can be seen that from 2015 to 2020, the standard deviation of the node strength of each province in the Yellow River Economic Belt shows a downward trend on the whole, which indicates that economic dependence in the provinces is developing towards a balanced trend on the whole. Furthermore, the gap between the node strengths of Inner Mongolia (No. 3), Ningxia (No. 4), and Qinghai (No. 5) on the one hand, and that of Henan (No. 2), Shandong (No. 6), and Sichuan

(No. 9) on the other, is gradually narrowing, which also shows that the implementation of the Yellow River Economic Belt strategy has promoted coordinated development in the region, especially in terms of the economic ties between the economically underdeveloped provinces and the other provinces in this region.

Based on the above analysis, we can see that the economic interdependence of the nine provinces in the Yellow River Economic Belt was quite different during different periods. In 2015 and 2016, with the overheated Chinese economy and the massive bubble in China's capital market, the interdependence was stronger. After the market was adjusted and resumed in 2017, the interdependence relationship between 2018 and 2019 was steadily raised. At the same time, the degree of economic interdependence between different provinces is not the same, among which the economically developed provinces—such as Henan (No. 2), Shandong (No. 6), and Sichuan (No. 9)—have stronger node strength, while the less economically developed areas—such as Inner Mongolia (No. 3), and Ningxia (No. 9)—are relatively weak. However, with the deepening of Yellow River Economic Belt strategy, the economic interdependence of the provinces in the region is gradually becoming more and more balanced, and the economic dependence of the less developed provinces on other provinces has been strengthened.

4.2. Maximum Spanning Tree

The MST is one of the spanning trees of a network with the maximum total edge weights. It can be used to help to disentangle the network and to visualize its key structures [54]. Figure 4 shows the MSTs in each of the six years, and the numbers represent the numbers of the nine provinces, as shown in Table 1. It can be seen that the structures of the trees are different.

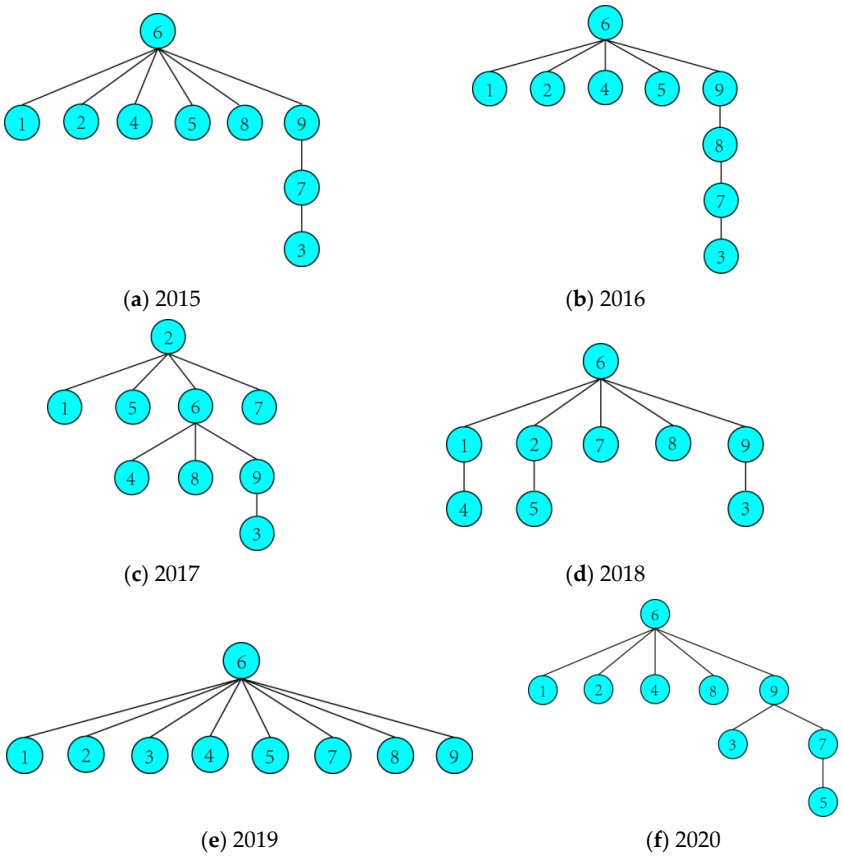


Figure 4. Maximum spanning trees (MSTs) of the nine provinces in each of the six years.

From Figure 4, we can observe that the No. 6 node always has the largest number of edges, followed by nodes No. 2 and No. 9, which also echoes the conclusions of

Section 4.1: that is, that Henan (No. 2), Shandong (No. 6), and Sichuan (No. 9) have strong economic ties with many provinces in the Yellow River Economic Belt. This proves once again the relationship between the level of economic development and the degree of closeness of development [34]. As provinces with higher levels of economic development, Henan (No. 2), Shandong (No. 6), and Sichuan (No. 9) not only have greater node strength (as shown in Figure 3), but also are at the core of the results of economic interdependence.

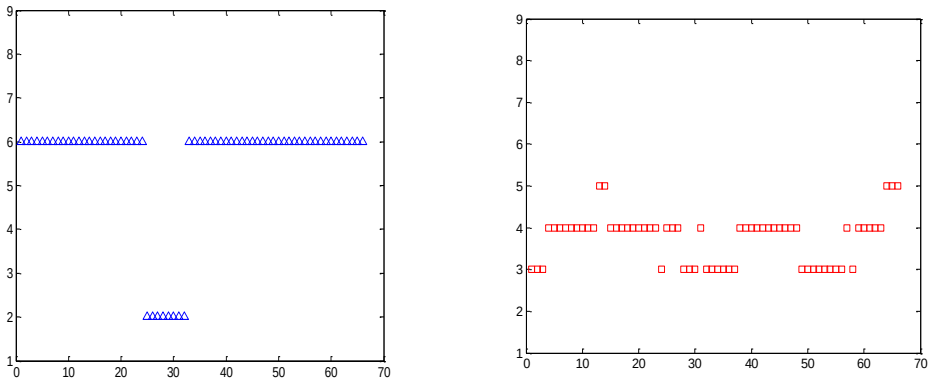
By analyzing the results of Figure 4, we can also draw another two interesting observations: First, that Shandong (No. 6), as the strongest economic province in the Yellow River Economic Belt—which is in third place in the Chinese mainland's total GDP rankings as of 2019—maintains strong economic ties with other provinces, especially in 2019, when Shandong had the strongest link with all of the other eight provinces. Secondly, that Shandong, as a province in the lower reaches of the Yellow River, is only adjacent to Henan in the Yellow River Economic Belt; from this point of view, the geographical clustering phenomenon—that is, strong interdependence between neighboring provinces or regions—is not obvious in the Yellow River Economic Belt, while each province appears more inclined to maintain strong links with the more economically developed provinces, such as Henan (No. 2), Shandong (No. 6), and Sichuan (No. 9). In addition, at some points, the economic interdependence of the provinces reflects a certain geographical clustering phenomenon—such as with Inner Mongolia (No. 3) and Shanxi (No. 7) in 2015 and 2016; Shanxi (No. 7) and Shaanxi (No. 8), and Shaanxi (No. 8) and Sichuan (No. 9), in 2016; Henan (No. 2) and Shanxi (No. 7) in 2017; and Gansu (No. 1) and Ningxia (No. 4) in 2018.

Based on the above analysis, we can gather that the economic interdependence of the nine provinces in the Yellow River Economic Belt does not strictly follow the geographical clustering phenomenon, whereby the neighboring provinces would maintain relatively close economic ties. On the contrary, the provinces prefer to maintain close economic interdependence with the more developed provinces—especially with Shandong Province, which is located in the eastern region.

4.3. Dynamic Evolution of Interependence

The previous analysis of the economic interdependence network and the core structure of the nine provinces in the Yellow River Economic Belt during the six years was a static analysis. This section will use the rolling window method to explore the dynamic relationships and structures of the economic interdependence of the provinces in the Yellow River Economic Belt. In this study, the width of the rolling window is set as 150 trading days, and the sliding distance of each window is set as 20 trading days. The reason for this setting of the window width and sliding distance is that it can not only guarantee the number of samples required for each window, but also guarantee that each slide is equivalent to one month, as well as guaranteeing a sufficient contrast effect. All samples are divided into 66 windows in total.

Figure 5 shows the provinces with the highest and lowest node strength in each rolling window. The abscissa represents the position of each window, while the ordinate represents the nine regional indices shown in Table 1. It can be seen from the figure that over the 66 windows, the greatest node strength is concentrated in two provinces—namely, Henan (No. 2) and Shandong (No. 6)—while the weakest node strength is concentrated in three provinces—namely, Inner Mongolia (No. 3), Ningxia (No. 4), and Qinghai (No. 5)—which is consistent with the results of previous static analyses.



(**a**) The greatest node strength (**b**) The weakest node strength

Figure 5. The regional indices with the greatest and weakest node strengths.

Table 5 shows, in each of the 66 sliding windows, with which one a certain region maintains the strongest dependence relationship—in other words, which region is most closely related to the window in question. For example, if the maximum weight of region A connects to region B, then we add 1 to the position of matrix (A,B), and the initial value of position (A,B) is 0. It can be seein in Table 4 that the table is not symmetric, because the maximum weight edge of region A may connect to region B, while the maximum weight edge of region B may connect to another region, such as region C, which leads to asymmetry.

Table 5. Total numbers of the strongest edges between the indices in rolling windows.

No.	1	2	3	4	5	6	7	8	9	Sum
1	0	13	0	0	0	48	0	0	5	66
2	0	0	0	0	0	66	0	0	0	66
3	0	6	0	0	0	8	23	0	29	66
4	15	6	0	0	0	35	4	4	2	66
5	0	29	0	0	0	26	8	1	2	66
6	0	38	0	0	0	0	4	1	23	66
7	0	17	9	0	0	22	0	6	12	66
8	0	6	0	0	0	46	0	0	14	66
9	0	0	0	0	0	66	0	0	0	66
Sum	15	115	9	0	0	317	39	12	87	

It can be seen from the table that the largest numbers among the top three provinces are Henan, Shandong, and Sichuan—of which Shandong has the largest weight edge 317 times, Henan 115 times, and Sichuan 87 times—and this ranking is consistent with the GDP of the three provinces among the Chinese mainland provinces. In addition, we can find that the region Shandong (No. 6) has the largest weight edge 317 times; among them, Henan (No. 2) and Sichuan (No. 9) each give the maximum weight edge to Shandong (No. 6) 66 times, while Shandong also gives Henan and Sichuan the maximum weight edge 38 and 23 times, respectively. It can be seen that among the nine provinces in the Yellow River Economic Belt, these three provinces with the best economic and social development maintain a strong economic dependence on one another, and other provinces also maintain the strongest ties with the above three provinces. In addition, Inner Mongolia, Ningxia, and Qinghai have the smallest number of largest weight edges from other provinces, and Ningxia and Qinghai do not have the largest weight edges from any other provinces, indicating that no provinces actively maintain the strongest economic interdependence with these two provinces. From the above results, it can be seen that the provinces with poor economic development are more willing to maintain a strong economic dependence on the provinces with more developed economies, or it can be explained that the provinces

with poor economic development are more dependent on the better developed economic provinces in matters of economic development, and the economic integration construction of the Yellow River Economic Belt can quickly enhance the economic growth of these provinces, so as to realize the economic growth and the balanced development of the whole region.

5. Conclusions

This paper focuses on the economic interdependence and the coordinated and sustainable development of the nine provinces in the Yellow River Economic Belt, and the changes to the economic interdependence structure over the past six years.

The research conclusions of this paper mainly include the following:

Firstly, there are extensive economic links between the provinces in the Yellow River Economic Belt, but the degree of economic interdependence varies greatly during different periods. When the economic development or the capital market is overheated, the interdependence of the provinces is stronger, while the interdependence decreases when the economic development is in a state of contraction or the total demand is relatively reduced. This shows that economic development and capital market operation have significant impacts on regional economic interdependence.

Secondly, the geographical clustering phenomenon of economic dependence is not obvious among provinces in the Yellow River Economic Belt. Most provinces maintain strong economic dependence on economically developed provinces, while economically underdeveloped provinces tend to be on the edge of the interdependence structure. In addition, the economically developed provinces also maintain strong economic ties with one another.

Finally, the implementation of the Yellow River Economic Belt strategy promotes coordinated and sustainable development in this region, especially the economic links between the less developed provinces and other provinces.

However there are still some limitations to this study. This paper studies economic interdependence and its core structure among the nine provinces in the Yellow River Economic Belt, but does not make a detailed analysis of the mechanisms of the dependence relationships or the core structure, which would be helpful in better explaining regional economic interdependence, and will be paid more attention in future research. Combined with the conclusions obtained in this paper, some suggestions could be drawn for the future development of the Yellow River Economic Belt. The most important thing is to pay attention to the economic driving role of the developed provinces, and at the same time pay more attention to the economic stability of the developed provinces, so as to prevent financial risks or economic bubbles from spreading to other provinces through the economic interdependence structure.

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