Hindawi
Complexity
Volume 2022, Article ID 3667745, 12 pages
https://doi.org/10.1155/2022/3667745

Research Article

Evolution of an Urban Network in the Yellow River Basin Based on Producer Services

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Received 17 August 2021; Revised 4 October 2021; Accepted 19 March 2022; Published 11 April 2022

Academic Editor: Ali A. Minai

From the perspective of the producer services, a chain network model describes the evolution of an urban network in the Yellow River Basin and its mechanisms. The findings indicate the following phenomena: the spread of urban network connections in the basin and the proportional structure of cities at all levels show the characteristics of "flattening." The network relationship within the basin has a clear spatial and hierarchical orientation, presenting a "core-periphery" network structure and a "polarisation to trickle down" development model. The spatial organisation of the urban network societies in the river basin is remarkable. The closeness of the societies shows a trend at first decreasing and then increasing. The boundaries of the associations are consistent with the provincial administrative boundaries. The formation and evolution of the urban network in the basin have passed through the initial agglomeration stage, the hierarchical network formation stage, and the hierarchical network consolidation stage. From the perspective of influence mechanisms, proximity mechanisms, socio-economic development, and advances in communication technology have significantly impacted the formation of the urban network structure in the Basin, while the level of science and technology education and the degree of openness to the outside world have had less influence on the promotion of network connections between cities.

1. Introduction

Globalisation and informatisation are profoundly affecting and reconstructing the global urban system, as manifested by the intensification and enhancement of spatial differences and connections [1]. The global expansion of multinational companies has accelerated the continuous weakening of regional boundaries, with the regional spatial organisation model gradually shifting from central locations that emphasise centripetal spatial organisation and top-down single vertical connections to networks that emphasise node nature and horizontal connections [2, 3]. In this process, the traditional "local space" was gradually replaced by a new, nonregional "flow space," and the global economic organisation became an "open and multilateral network" [4, 5]. The formation of such a complex network produces a broader spatial influence that focuses cities of different natures, grades, and scales into the same networks and plays the functions and values of their respective nodes under the guidance and action of flow space [6].

As the best metaphor for the complex relationship between social actors in the new context, network research has become an increasingly important frontier of urban and economic geography [7]. In the early stages, the spatial image of the urban network was drawn mainly as a tangible physical network, with the traffic flow, such as highways, ports, railways, and aviation, as the focus of the research [8–10]. With the rise of the Internet, analysis of urban networks based on information flows such as mail, Internet traffic, and network broadband traffic began to emerge [11, 12]. The advent of the knowledge economy has led to the growth of innovative cyberspace with cities as the hubs, and the impact of intercity knowledge and technology flows on the urban network system gradually attracting the attention of the academic community [13–15]. In recent years, big data, represented by social networking site data [16], bus swiping data [17, 18], cell phone signalling data [19, 20], taxi GPS data [21], Weibo check-in data, and Baidu migration data [6, 22, 23], have provided more diversified support for modern urban network analysis. Under the influence of the central place theory, the hierarchical division of traditional urban systems has been mainly divided along with the perspectives of scale, grade, and urban function. The measurement method is mainly based on a large number of urban attributes and stresses urban internal characteristics and functions, ignoring the horizontal and mutual cooperation between cities [24]. Apart from this, some scholars have initiated discussions on the evolution of urban networks. With regard to the evolutionary mechanisms of urban networks, economic globalisation and regional economic integration have accelerated the industrial upgrading of central cities [25, 26]. As hubs of R&D institutions and headquarters, some cities have seen a huge rise in their role in regional development [27]. Overall, although these studies illustrate the external functions of producer services in the context of globalisation and informatisation in the formation of China's urban system, they have failed to further explore the evolution of urban networks from the perspective of productive service enterprises in the basin scale.

The cross-regional layout of corporate organisations and the networked development of organisational relationships have strongly promoted the formation of urban networks. The analysis of corporate microbehaviours with a worldwide layout has become an important entry point for studying world urban networks. In the new international division of labour, the disadvantages of the manufacturing industry for meeting the needs of structural transformation and product innovation have been prominent [28]. In this process, producer services have become an important driving force for the formation of metropolitan networks and an effective tool for explaining interurban connections. Research on the introduction of producer services into urban networks originates from Western scholars' attention to the world city system [29]. Relying on the production service company headquarters-branch network, Peter Taylor built the interlocking network model and took the lead in analysing the world city network with production service company data [30]. Western scholars' research on producer service city networks involves many aspects, such as world city networks and national and regional network patterns [31–33]. Their research perspectives are not limited to producer services themselves [11], but internal research on different industries is becoming increasingly abundant [34]. Influenced by Taylor's theory of world city networks, the research on city networks based on producer services is also gradually advancing in Chinese academic circles. Associated scholars mainly focus on the correlation between producer services, economic development, and the characteristics of urban networks. The research scope includes not only the national level [35] but also the urban system in the Yangtze River Delta [36], the urban network in Chengdu-Chongqing region, and the urban system in the Pearl River Delta [37, 38]. These empirical studies enrich the research results of China's urban regional scale and also strongly explain the outward function of producer services in the formation of the urban system in China against the background of globalisation and informatisation.

China upgraded ecological protection and high-quality development of the Yellow River Basin to a major national strategy in September 2019, setting a new goal for the development of the basin. The essential connotation of high-quality development is high efficiency, fair, green, and sustainable development is based on meeting the people's ever-increasing need for a better life [39]. As a spatial and regional unit comprising economic elements and social and economic activities, a watershed's high-quality development is not only the spatial implementation of high-quality economic development but also the external manifestation of coordinated social and economic development. Due to the existence of natural links, the interests of the development within the basin often form consistency, so promoting the integrated development of the basin often becomes the internal requirements of the basin development [40]. The Yellow River Basin is an important economic zone in China, and the strategic value of producer services for industrial transformation and coordinated economic development in the basin is increasingly prominent. From the perspective of productive service enterprises, this paper discusses the evolutionary characteristics, patterns, and mechanisms of urban networks in the Yellow River Basin. We hope to enrich the case study of urban networks of the Yellow River Basin, deepen the theoretical understanding of the spatial structure of it, and provide scientific basis for realising its high-quality development.

2. Data Sources and Methods

2.1. Overview of the Study Area. The Yellow River originates from the "water tower of China" in the source of the three rivers (Yellow River, Yangtze River, and Lancang River), as it passes through the Qinghai-Tibet Plateau, Inner Mongolia Plateau, Loess Plateau, North China Plain, and other topographic areas, and crosses the plateau mountains, temperate continental and monsoon climate zones, and arid, semiarid, and semihumid precipitation types. The comprehensive effects of natural elements such as topography and climate have given birth to the unique drainage structure of the Yellow River Basin: the upper and middle reaches of the river are ecologically fragile, and the environment has become a key constraint on the development of the basin. There are few large-scale tributaries, and the downstream section of the suspended river is linear. These fail to form a complete river network system, thus blocking the social and economic connections between the upstream and the downstream and between the basin and the outside. Based on the National Ministry of Water Resources of the Yellow River Water Resource Commission designated natural range, from its economic standpoint, the integrity of the basin to the eight provinces of Qinghai, Gansu, Ningxia, Inner Mongolia, Shaanxi, Shanxi, Henan, and Shandong and the statistical calibre of consistency, data availability, and comparability, 65 district cities were eventually chosen as research subjects.

2.2. Data Source and Processing. First, we used the regional keyword query function provided by the 11315 National Enterprise Credit Information System (https://www.11315.com/infnews/) and entered such keywords as "subsidiary" and "branch" to obtain the names of the internal branches in the research area and their corresponding company headquarter directories. Second, we logged on to the website of the State Administration for Industry and Commerce (https://www.gsxt.gov.cn/index.html) and use the company directory to perform a second query to supplement the company-attributed information. A total of 1,025 pieces of corporate data in 65 prefecture-level cities in the basin were obtained through sorting. Based on the obtained spatial locations of corporate headquarters and branches, only samples of corporate headquarters and branches in different places were kept. Finally, the sample enterprises were classified according to time. Those from 2000, 2010, and 2020 were screened out, and a total of 6953 valid samples were finally obtained.

2.3. Research Methods

2.3.1. Chain Network Model. In this paper, the connection strength of the network mainly refers to the connection strength between cities. The comprehensive network connection strength between city a and city b can be expressed as follows:

$$N_{ab} = L_{ab} + L_{ba}, \tag{1}$$

where N_{ab} represents the strength of the connection between cities a and b, L_{ab} is the total number of enterprises with their headquarters in city a and corresponding branches of each headquarters in city b, and L_{ba} is the opposite vector value. The higher the total connectivity of a city, the better it can be integrated into the whole network of producer services.

The relative network connectivity for a single city can be expressed as follows:

$$P_a = \frac{N_a}{N_h}, \tag{2}$$

where N_a represents the total connectivity between city a and other cities in the network, and N_h is the city with the highest total network connectivity.

2.3.2. Community Detection. Community discovery can reflect the local characteristics of individuals in a network and their relationships and analyse and predict the interactions between elements of the entire network. Among them, the module-degree calculation method proposed by Newman is often used to measure the division quality of online communities [41]. The formula is as follows:

In the formula, Q is the function of module degree, which quantitatively measures the result of community division. M is the total number of network edges, while A is the adjacency matrix corresponding to the network. When $A_{ij} = 1$, there is an edge between points i and j. Otherwise, there is no edge. K_i is the degree of node i; C_i is the label where node I belongs to a community.

2.3.3. QAP Analysis. This paper uses the Quadratic Assignment Procedure (QAP) as a nonparametric test method to quantitatively reveal the influence mechanism of the evolution of the urban agglomeration community structure. Compared with conventional statistical testing and regression methods, its advantage is that it does not need to meet the conditions of independence or noncollinearity between independent variables. The results obtained are more reliable, which is very suitable for the analysis of relational data. There are three specific analysis steps: first, select a number of influencing factors based on related theories, and research and build a model with the index network as the independent variable and the production service company's associated network as the dependent variable; second, use QAP correlation analysis to test the correlation between the company's associated network and the index network; and finally, eliminate the factors with insignificant coefficients in the QAP correlation analysis. The remaining factors and dependent variables are subjected to QAP regression analysis to obtain the regression coefficients and test the indicators of each variable.

3. Analysis of the Urban Network Structure of the Yellow River Basin

3.1. The Evolution of the Hierarchical Spatial Structure of Network Nodes. The spatial level of nodes can better reflect the status and role of the city in the watershed than the traditional classification of the city hierarchy. In this paper, the score of the relative connectivity P_a between different cities is used as the measurement for the classification of the city hierarchy. Comprehensively use the Q-type clustering method of SPSS19.0 hierarchical clustering to cluster 65 cities into 5 categories (Table 1).

From the hierarchical structure of urban network nodes, the network of producer service enterprises in the Yellow River Basin presents a clear diffusion trend, with the proportion structure of cities at all levels presenting a "flattening" feature. In this process, the number of cities in the first level of network connectivity rose from one in 2000 to four in 2020, as provincial capitals such as Taiyuan and Xi'an in the middle and upper reaches of the basin gradually became the central nodes of regional network connection. The reason may be that the middle and upper reaches of the Yellow River Basin are rich in natural resources and are home to a large number of traditional industries. In the process of China's industrial transformation and upgrading, modern emerging service industries with high knowledge-intensive characteristics have achieved rapid development in the middle and upper reaches of the river basin. Especially since 2010, with the continuous improvement of the development level of the producer services industry, those companies have gradually expanded in the central and western regional cities. Some provincial capitals in the middle and upper reaches of the basin, such as Taiyuan and Xi'an, have also joined the ranks of the first tier, as the network structure of cities in the basin has been further optimised. From the perspective of five different levels, the status of nodes in the intracity network of some cities is inconsistent with the characteristics of the traditional city hierarchy. For example, prefecture-level cities such as Tai'an, Jining, and Weifang have assumed the role of regional

Table 1: Hierarchical distribution of urban nodes based on producer services.

Level	2000	2010	2020
The first	Jinan (1)	Jinan (1)	Jinane, Zhengzhou, Taiyuan, Xi'an (4)
The second	Taiyuan (1)	Weifang, Taian, Zhengzhou, Taiyuan, Xi'an, Lanzhou (6)	Jining, Weifang, Lanzhou (3)
The third	Zhengzhou, Huhehot (2)	Dongying, Zibo, Jining, Liaocheng, Jiaozuo, Linfen, Huhehot, Xining (8)	Zibo, Taian, Liaocheng, Huhehot, Yinchuan, Xining (6)
The fourth	Xi'an, Yinchuan, Lanzhou (3)	Heze, Shangluo, Shangqiu, Xinxiang, Jincheng, etc. (21)	Dongying, Binzhou, Heze, Shangqiu, Luoyang, Yuncheng, etc. (12)
The fifth	Weifang, Zibo, Luoyang, Baiyin, etc. (58)	Binzhoui, Kaifeng, Luoyang, Shuozhou, Yulin, etc. (29)	Puyang, Kaifeng, Xinxiang, Yulin, Guyuan, Dingxi, Haidong, etc. (40)

Note: The number in brackets is the number of cities.

network contact centres, whereas provincial capital cities such as Xi'an, Yinchuan, Xining, and Lanzhou are no longer as prominent in the urban network. To a certain extent, this reflects the reality that the expansion of the urban network based on producer services does not completely follow the existing administrative hierarchy system based on geographical space.

From the perspective of the spatial distribution of urban network nodes in the Yellow River Basin, the city network's level distribution at the three time nodes all presented a "core-peripheral development model" (Figure 1). Before 2000, the distribution of high-level network nodes in the basin was relatively scattered and mostly located in the middle and lower reaches of the river basin, while the central cities in the upstream region were relatively low in the node level of the urban network. This further shows that the development of the producer service industry in the basin during this period was incomplete, leaving an extremely uneven intensity of urban connections between the upper and lower reaches of the basin. The distribution of urban network nodes in the river basin in 2010 changed considerably compared with 2000. The scale of producer services and the strength of intercity connections in some provincial capital cities, such as Xi'an, Lanzhou, and Xining, located in the middle and upper reaches of the river, have grown rapidly, with the Yellow River Basin initially showing a phenomenon of the "strong provincial capital." In this process, the middle and lower reaches of the river basin have become high-level and relatively concentrated network nodes, showing obvious spatial agglomeration effects. The reason may be that the producer services in this region not only have enjoyed a relatively high-level development but also have a sound basis for external output and play an important role as a network hub. In addition, Taiyuan, Linfen, and Xi'an in the middle reaches of the river basin, along with Lanzhou, Xining, and Huhehot in the upper reaches, also showed certain characteristics of agglomeration of producer services. The provincial capital cities in the basin showed a strong "leading" trend heading into 2020, with a development trend of "strong provincial capital." There was also a certain degree of differentiation within provincial capital cities. Provincial capital cities such as Zhengzhou, Xi'an, and Lanzhou grew rapidly compared with other prefecture levels in their provinces, producing a certain "siphon effect."

3.2. Hierarchical Structure Evolution of Network System. In order to further clarify the role of node cities in the river basin network system and the laws of their spatial connections, the natural breakpoint method is used in the ArcGIS software to divide the strength of intercity connections into three levels, creating a city network hierarchy diagram (Figure 2).

Through analysis, it is found that the urban network of the three time periods in the basin presents a continuous hierarchical structure, with its agglomeration and evolution showing obvious spatial orientation and "path dependence." In 2000, the overall network connection between cities in the basin was weak, with a network density of 0.017. A complete urban connection network had not yet been formed. The first-level city network was limited to the downstream areas, forming a four-pair association sequence of Jinan-Laiwu, Jinan-Liaocheng, Jinan-Weifang, and Jinan-Jining, with Jinan at the core. The second-level network was mainly distributed in the middle and upper reaches of the river basin, including Taiyuan-Jincheng, Hohhot-Ordos, and Hohhot-Bayannur. It can be seen that the network connection at this level is mainly within the province, and the spatial coordination between regions needs to be strengthened. The three-tier city network connections are mainly concentrated in some neighbouring cities with Lanzhou and Xining as the core, and Yinchuan and Xianyang, Lanzhou and Xining, and Xining and Yinchuan also forming spatial connections, with cross-provincial connections beginning to appear. In 2010, network connections between cities in the basin were significantly enhanced compared with the previous period. Its network density reached 0.091, and the radiation range of regional central cities increased, forming a multicentre network connection expansion structure with provincial capital cities as the core. Among them, the first-level network expanded to the middle and upper reaches, forming a total of 45 pairs of association sequences represented by Jinan-Weifang, Zhengzhou-Shangqiu, Taiyuan-Linfen, Xi'an-Lanzhou, and Lanzhou-Xining. The secondary city network has formed 10 pairs of sequences. In the connection direction, it shows that the provincial capital city is the radiating centre and spreads to the neighbouring cities. At the same time, the interprovincial city connections gradually strengthened. The three-tier city contact network during this period increased from 17 pairs in 2000 to 45 pairs, and the main framework of the network

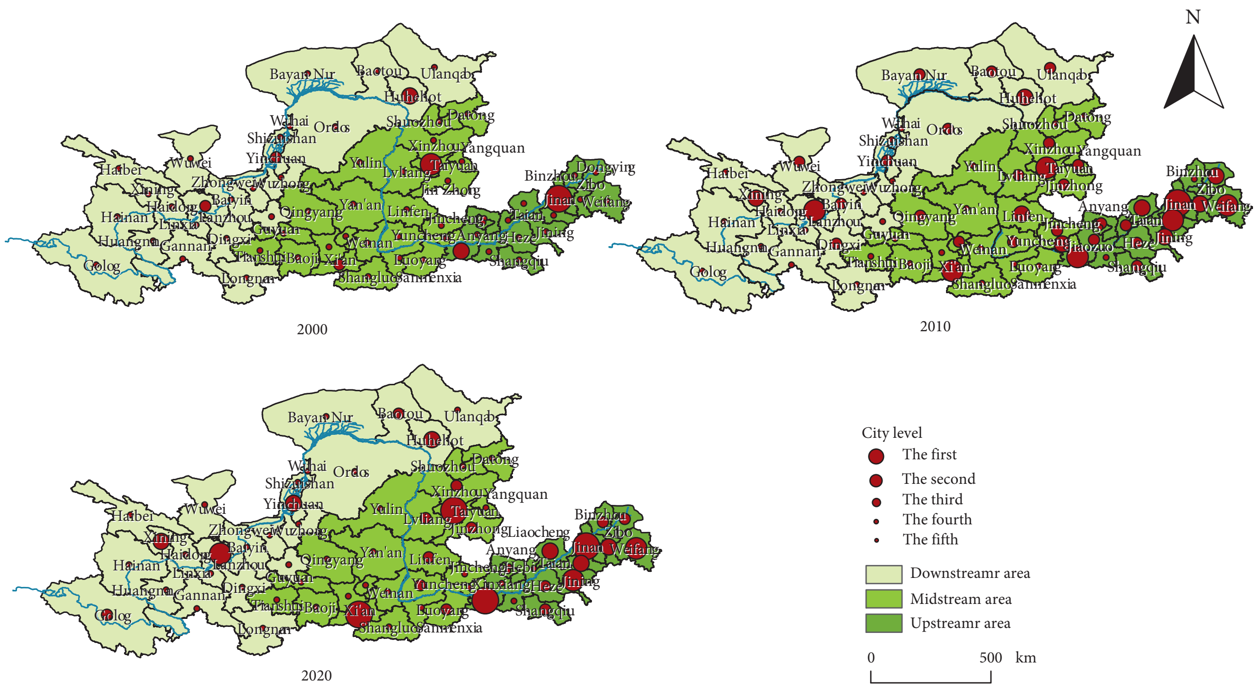

FIGURE 1: Hierarchical distribution map of river basin urban network nodes.

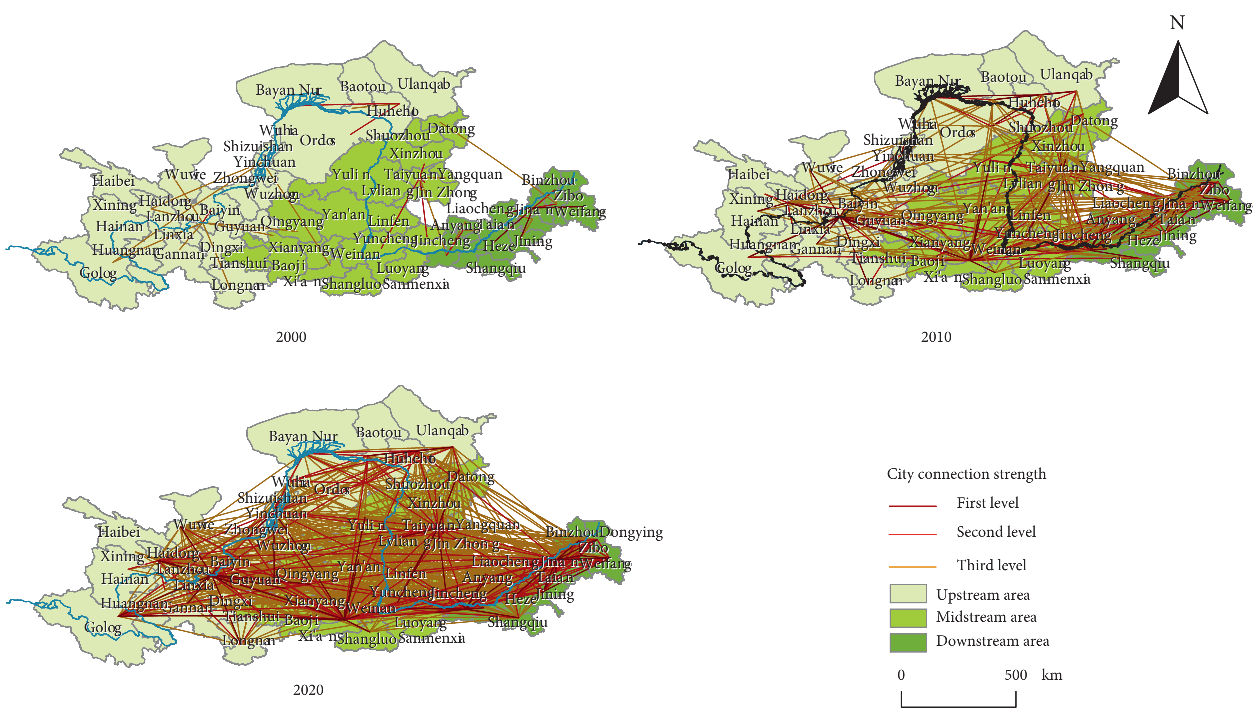

FIGURE 2: Hierarchical distribution of urban network in river basin.

structure between cities in the river basin was basically formed. In 2020, the overall network density in the river basin will reach 0.229, and the degree of urban network connections will be further improved, tightening the connections between cities. Through analysis, it is found that, compared with the previous period, the high-level urban network connection during this period has developed rapidly in the basin, while the urban network structure has basically remained stable, with the traditional core cities still playing leading roles.

3.3. The Evolution of Network System Community Structure. The *UCINET* software is used to calculate the urban modularity of the Yellow River Basin at three time nodes, and the network communities are divided accordingly. The number of splits of the association network was set as 2~15 times, and the modularity of different splits was calculated to determine the best classification of the community structure. The splitting times of the three time nodes are 7, 8, and 10, respectively, with the corresponding modularity the largest, which means that the division effect of urban communities is the most ideal. Through measurement, it was found that the maximum modularity of the three time nodes reached 0.781, 0.520, and 0.864, respectively, indicating that the urban association network of the Yellow River Basin is highly differentiated and presents a highly significant characteristic of the spatial organisation mode of community. On the whole, in the research period, the closeness of associations among communities in the basin showed a trend of first decreasing and then increasing, with the internal contact density of various associations increased.

By analysing the spatial organisational characteristics of various communities in the basin, their boundaries were highly consistent with the provincial administrative limits, denoting their status in the basin as a process of dynamic adjustment (Figure 3). Through analysis, it is found that seven community groups with Jinan, Zhengzhou, Taiyuan, Xi'an, Yinchuan, Hohhot, and Lanzhou as the core were formed in the basin in 2000, and the hierarchical gap between the community groups was relatively small during this period. Compared with the previous period in 2000, the producer service industry in 2010 has developed significantly in the upstream central cities. During this process, Xining City played an increasingly prominent role in regional connections and the formation of new community groups, leading to the growing status of the Xi'an and Lanzhou communities in the basin. In 2020, the Xi'an community in the upstream region continued the previous arrangement. Its status has been continuously promoted to become the highest-ranking community in the network. With the deepening of the degree of urban network connections in the river basin, the network connections within the community have differentiated, leaving some prefecture-level cities to gradually separate from the original community system and form new community groups.

4. Division and Model Induction of the Evolutionary Stages of Urban Network in the Yellow River Basin

Combining the regional development stage and related theories of industrial development, the formation and evolution process of the urban network in the Yellow River Basin during the study period is presented in three stages. In order to effectively reveal the evolution patterns and types of the urban network structure of the Yellow River Basin from the perspective of the producer service industry, the network structure patterns formed in three different stages are summarised thusly (Figure 4):

(1) The budding stage of hierarchical networks (pre-2000). The process of industrialisation is often accompanied by the continuous evolution of the internal structure of the producer service industry. Since various activities of the producer service industry were mainly provided by manufacturing enterprises in the early stages of industrialisation, the manufacturing industry in the Yellow River Basin during this period was largely dominated by labour and capital-intensive manufacturing, leaving the industrial structure low. Therefore, when the overall demand for production materials in the manufacturing industry in the basin is not strong, its producer service industry is also at a relatively low level of development. At this stage, the existing service activities in the Yellow River Basin were mainly concentrated in the regional central cities, and most of the service activities were rarely linked between provinces. Limited by the level of transportation infrastructure and communication technology at this stage, contacts between producer service companies occurred mainly by sending staff to contact local departments. The expansion of the companies within the region was not obvious. In this process, although the service function of regional central cities in the basin was strengthened, the driving effect on the surrounding cities was not strong and the service function differences were prominent. The whole region presented a system model of single centre development.

(2) Hierarchical network formation stage (2000-2010). With the refinement of the industrial division of labour and the development of economies of scale, especially the needs of manufacturing service model innovation and industrial transformation and upgrading, the producer service industry began to separate and grow independent from the manufacturing sector. From the perspective of enterprise space expansion, during this period, producer service enterprises in the Yellow River Basin increased their demands for information acquisition in the process of scale growth, the strength of network connections between cities increased, and a horizontal flow trend appeared. The producer service industries of cities with lower levels in the basin gradually began to develop, and the trend of multicentre development initially appeared. In the process, the spatial diffusion of producer service enterprises in the basin was enhanced, and the hierarchical characteristics of urban networks grew more and more obvious. On the whole, the connections between node cities in the basin during this period showed a trend of interweaving vertical and horizontal connections, while its spatial structure showed flattened characteristics.

(3) Consolidation stage of the hierarchical network (2010-present). After entering the middle stage of industrialisation, as China's economy gradually shifted from a manufacturing-oriented to a service-oriented economy, the producer service industry gradually became an important force in instigating urban economic growth and a major player in urban

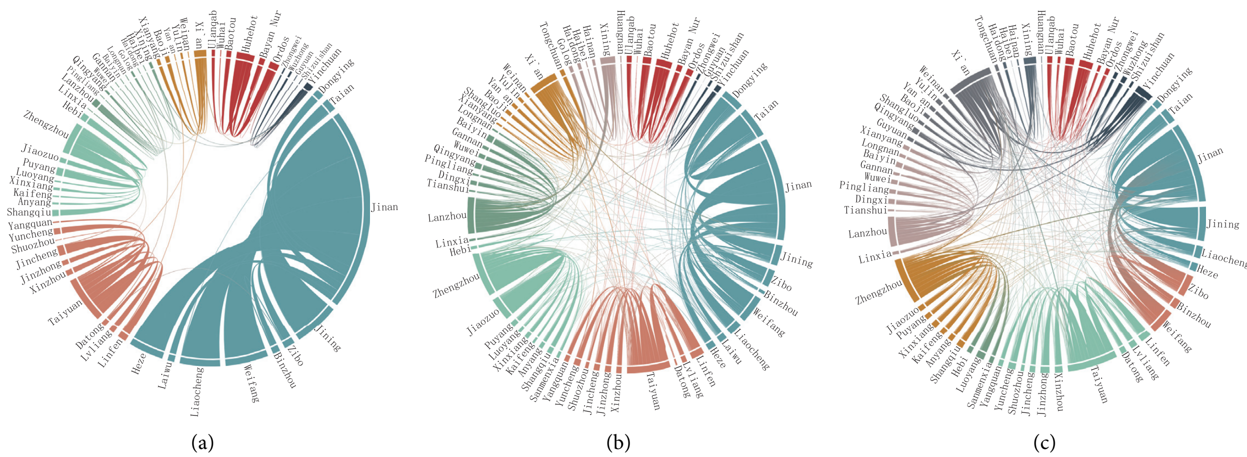

Figure 3: Evolution of urban network structure in the Yellow River Basin. (a) 2000. (b) 2010. (c) 2020.

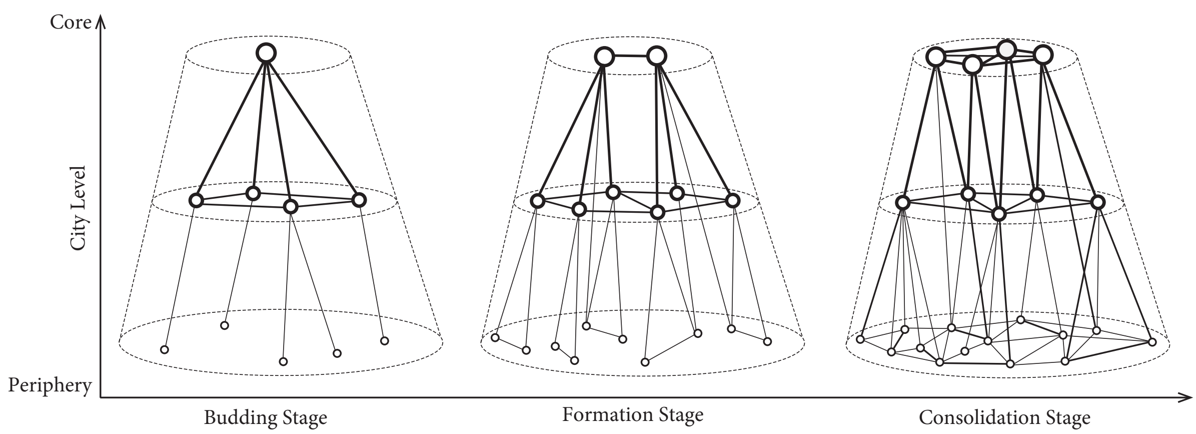

Figure 4: Model induction of the urban network of the Yellow River Basin in each evolutionary stage.

economic functions. Under the post-ford-style, flexible production organisation system, the international division of labour began to transform from product division to element division, and the organisation and management of enterprises in the basin gradually shifted from a functional layout structure to a multisegment structure. As the organisation and management of each branch were relatively complete and self-contained, this organisational structure also became more diffuse. At the same time, diseconomies of scale led to the transfer of some elements from high-level cities to low-level cities. Some nonadministrative central cities within the river basin enhanced the agglomeration and radiation capabilities of the elements, the horizontal connections became more significant and the urban network further consolidated. During this period, the hierarchical characteristics of the urban network in the basin became more and more obvious, the horizontal connections grew closer as the connection directions became more diverse, and the gap in service function connections narrowed.

5. The Influence Mechanism of the Evolving Urban Network Structure in the Yellow River Basin

5.1. Variable Selection. Based on the macroinfluencing factors and mechanisms in the existing literature, and taking into account the microbehaviour characteristics of producer service companies, the following variables are selected:

(1) Nearby mechanism variables. ① The proximity of policy systems. Considering that there are multiple administrative system environments in the river basin, different environment systems may have an impact on the development of enterprises. In this paper, 1 and 0 are used to indicate that the two cities belong to the same province or different provinces, reflecting the system proximity effect produced by interprovincial administrative divisions; ② Geographical proximity. Calculate the physical distance between cities based on the straight-line distance between them. Considering that the actual geographic distance between cities

may be too large and may cause errors in the estimation results, the actual distance is processed based on the research results of relevant scholars. ③ Cultural proximity. Local-scale economic connections are usually achieved through face-to-face informal communications. The cultural similarity is conducive to communication and coordination, which is of positive significance for the development of the producer service industry. Dialects are an important cultural representation in China. Among them, there are the many regional types of dialects in the Yellow River Basin, involving seven dialect areas. In view of this, use 1 and 0, respectively, were used to indicate that the two cities belonged to the same dialect area and different dialect areas, respectively, to reflect cultural proximity [42]. ④ Industrial proximity. In order to reflect the impact of the degree of similarity of similar industrial structures between cities in the river basin on urban economic relations, according to the industry classification in the city statistical yearbook, the industrial structure similarity coefficient is used to reflect the industrial proximity.

(2) Other variables. ① Social and economic development status. The population size is represented by the total population of the municipal area. The economic scale is represented by the GDP of the municipal districts. ② The level of science and technology education. The Intellectual capital is represented by the product of the number of scientific research and technical services of 10,000 people in the municipal area and the city's per capita local financial science and technology expenditures. The producer services is knowledge, technology, and capital-intensive industry. The easy access to required human resources is an important key factor in the location selection of producer service enterprises. Therefore, this article uses the average years of education to reflect the distribution of human resources. ③ Progress in technological exchanges. Select the accessibility index to characterise the progress of transportation technology. The total volume of post and telecommunication businesses is selected to reflect the progress of communication technology. ④ Openness to the outside world. The degree of openness to the outside world is an important indicator to measure the development level and scale of a country or region in international economic activities and its dependence on the global economy. This article mainly uses two indicators to characterise foreign trade dependence and foreign investment dependence [43]. Among them, the degree of dependence on foreign trade focuses on measuring the extent of the export-oriented national economy of prefecture-level units; the degree of dependence on foreign investment mainly reflects the degree of capital openness of prefecture-level units and the size of the potential for foreign economic development.

5.2. Regression Analysis. In QAP, correlation analysis examines whether the variables have collinearity, and regression analysis examines whether the influencing factors are significant. It was found through measurement (Table 2) that the correlation between most factors and the associated network of producer service companies over the course of the three years passed the 1% significance level test. With R^2 between 0.5 and 0.6, the model has achieved a relatively good fitting effect.

The results confirm that the proximity mechanism had a significant impact on the formation of the urban network structure in the Yellow River Basin and that the degree of influence on the urban network structure varies at different stages. Among them, the proximity of the administrative system based on the division of provincial administrative units is significantly positive in the three periods, indicating that administrative proximity strengthened the connection between the units. Although the regression coefficient of geographical proximity has passed the significance test in different periods and had a positive effect, with the development of transportation and information technology, its influence on the network relationship of producer service enterprises has gradually weakened. Cultural proximity is significantly positive in different periods, indicating that the smaller the regional dialect and cultural differences, the stronger the cultural identity between microindividuals, and the less likely it is to produce cultural conflicts, which are beneficial to the formation of regional internal connections. Although industrial proximity contributes to the improvement of regional specialisation and the exertion of the agglomeration effect, the positive influence on the formation of regional network connections is weak. In addition, because the influence of the dimension is eliminated, the size of the regression coefficient reflects the strength of the influence. Through measurement, it is found that institutional proximity has the largest coefficient in both the proximity mechanism variable group and all factors. The above results show that the formation of the urban network organisation relationship in the provincial administrative boundary region bears an important influence as the biggest obstacle to the regional network connection.

In the socio-economic development variable group, the two variables have passed the significance test in different periods, indicating that the radiation effect brought by the city's socio-economic development has promoted the network connection between cities. In the variable group of science and technology education levels, the regression results of knowledge capital and human resource distribution are not significant, indicating that a significant role for human and knowledge capital in the development of the producer service industry has not yet appeared. The reason may be that long-term, low-end manufacturing in the Yellow River Basin has dampened the development level of

Table 2: QAP analysis results of the evolution of urban network structure in the Yellow River Basin.

Variable group	Variable	Network formation stage		Hierarchical network formation stage		Network form consolidation period	
		Related analysis	Regression analysis	Related analysis	Regression analysis	Related analysis	Regression analysis
Proximity mechanism	System proximity	0.186***	0.027*	0.083***	0.032**	0.137***	0.053***
	Geographical proximity	−0.195***	−0.253**	−0.059***	−0.176*	−0.106***	−0.065***
	Cultural proximity	0.057***	0.068**	0.074**	0.053**	0036***	0.050***
	Industry proximity	0.859***	0.032**	0.153**	0.095***	0.217***	0.062**
Socio-economic development	Economic scale	0.118***	0.109***	0.017**	0.083***	0.023***	0.136***
	Population size	0.291***	0.057***	0.156***	0.085***	0.142**	0.181***
Science and technology	Knowledge capital	0.075**	0.109**	0.108**	0.168*	0.095***	0.049**
	Human resource distribution	0.094**	0.072***	0.155**	0.129**	0.106***	0.083
Communicating technological progress	Progress in transportation technology	0.075***	0.127***	0.130***	0.019***	0.083***	0.228***
	Communication technology progress	0.263**	0.159***	0.020*	0.144**	0.152***	0.094*
Degree of openness	Foreign trade dependence	0.165**	0.052	0.065*	0.148*	0.179**	0.157**
	Foreign capital dependence	0.152**	0.049	0.084**	0.024**	0.218***	0.039*
	Sample size	65	65	65	65	64	64
	R^2	—	0.60	—	0.58	—	0.52

Note: ***, **, and * are significant at the statistical levels of 1%, 5%, and 10%, respectively.

the supporting producer service industry and that the two have fallen into a potential internal low-end lock-in cycle. This leads to the insignificant role of regional knowledge capital and human resources in the development of the producer service industry and the promotion of the value chain. In the communication technology progress variable group, both variables passed the significance test, indicating that the space-time compression effect produced by transportation technology progress promotes the connection between cities in the basin. The production service industry in areas with a higher level of information technology will have more information resources and lower information transmission costs, thereby attracting more producer service companies to deploy here. Through measurement, it is found that the variable of openness to the outside world has not passed the significance test. The reason may be that the overall globalisation process of the Yellow River Basin is relatively slow, the export-oriented economy is not prominent, and it has not had a significant effect on the network connections between cities in the basin.

6. Conclusions

Economic globalisation and the rapid development of information technology have strongly promoted the formation of urban networks. As the main driving force of structural transformation and an important source of product innovation, the key role of producer service enterprises in this process has received greater attention. Based on headquarters-branch data of producer service enterprises in different years, this paper uses the network analysis method to analyse the urban spatial structure of the Yellow River Basin. The main conclusions are as follows:

(1) The urban network in the Yellow River Basin has hierarchical stratification and path dependence under the influence of urban rights, presenting a "core-periphery" network structure and a "polarisation to trickle" development model. With the transformation of the organisation and operation mode of producer service enterprises to networks, the network connection among cities with producer service enterprises as the link has an obvious diffusion trend, and the proportional structure of cities at all levels demonstrates the characteristics of "flattening." In addition, the urban association network of the Yellow River Basin has formed a substantial spatial network of community groups. The status of each community in the basin is in a dynamic adjustment process, and the closeness of associations between communities has shown a trend of first decreasing and then increasing.

(2) Based on the urban administrative hierarchical system of geographic space, careful consideration is given to the spatial expansion process of producer service enterprises. Through inductive analysis, the formation and evolution of the city network based on the producer service industry are summarised as three stages, namely, the initial agglomeration stage, the network formation stage, and the network consolidation stage. At present, the overall urban

network of the Yellow River Basin, based on producer service enterprises, is at a point of consolidation of the hierarchical network. Its main characteristics are that the urban network has become more obvious, the horizontal connections are increasingly close, the connection directions are more diverse, and the service function connection gap is narrowing.

(3) From the perspective of influence mechanism, geographical, cultural, and administrative proximity have all cast a significant impact on the formation and evolution of urban networks in the basin, with administrative proximity having the greatest impact. Advances in communication technology and socioeconomic development have also carried a significant impact on the internal and external relations of the community. Under the combined effect of many factors, the urban network structure of the Yellow River Basin is becoming more and more refined from the perspective of producer service enterprises, with the horizontal connections between cities constantly increasing.

7. Discussion

The formation and evolution of the urban network structure denote a coupling process of two basic forms of movement, namely, spatial aggregation and diffusion. With the further division of labour, enterprises demonstrate multisectoral and multiregional tendencies, whereas changes in enterprise networks exert a direct influence on the spatial evolution of urban networks. Moreover, the most direct embodiment of the role of enterprise networks in urban networks is that the choice of an enterprise to enter or exit a city can result in a change in its position in the urban network. As a crucial driver of economic growth and industrial chain upgrading in cities, developing producer services displays a profound significance in strengthening intercity exchanges and cooperation and in promoting the efficient and orderly growth of regional urban systems. The relationship between enterprises and cities involves among different locations of enterprises and their branches, choice of enterprises regarding new investment sites and efforts of cities to attract enterprises by making themselves more competitive. Governments play a critical role in the clustering of enterprises and the development of industries. Furthermore, they drive the expected returns of enterprises. Therefore, they intervene in the decisions of enterprises by formulating policies and plans that facilitate industrial development, optimising support conditions, and improving supporting infrastructure. Additionally, the decisions of enterprises are largely influenced by the conditions of their cities (i.e., scale characteristics, such as population size, economic characteristics, infrastructure construction, informatisation level, human capital, and innovation factors) and their position in the urban system.

In the Yellow River Basin, the urban network system connected by producer services is expected to become increasingly *flat* with the diversification of production activities and the networking of producer services. This notion suggests the increased connectivity of urban networks. Interprovincial interaction and networking are currently mainstream in the Yellow River Basin, with central node cities exerting the siphon effect on the urban network. Hence, coordinated development between regions within the Basin to improve its urban network should be emphasised. At the national level, the Yellow River Basin can improve the quality of regional cooperation, except for internal cooperation, by increasing links with its neighbours and developed regions at home and abroad based on the local conditions. Additionally, it should aim to address imbalances and inadequacies in regional development, formulate relevant strategies that are more interconnected and holistic, and enhance its coordination and integrity. At the local level, efforts should be undertaken to improve synergies between cities in the Basin with core cities radiating and promoting the surrounding areas. Presently, core cities exhibit a major agglomeration effect but a poor positive spillover effect. This tendency inspires the breakdown of *barriers* between cities, strengthens synergy, and leverages the radiating and driving role of central cities. Furthermore, cities along the Yellow River Basin, especially those in the middle and lower reaches, should utilise their ecological resources to realise industrial complementarity between provinces and regions within the Basin. In this manner, they are "optimising the stock and improving the increment." This initiative is expected to promote the transformation of industrial structure from low-end to high-end. Moreover, it is expected to build an industrial cooperation alliance along the Yellow River Basin with the Yellow River as the link, cities as the carrier, and mutually beneficial cooperation as the premise. As a result, the restraints of the administrative region economy can be overcome, and a joint force for overall regional performance can be created.

Data Availability

The basic data come from the 11315 National Enterprise Credit Information System (https://www.11315.com/infnews/) and the China State Administration for Industry and Commerce website (https://www.gsxt.gov.cn/index.html). The final data used to support the findings of this study contain confidential trade information, while the research findings are commercialised. Requests for sample data, 6 months after publication of this article, will be considered by the corresponding author.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Acknowledgments

The authors thank the Key Program of National Natural Science Foundation of China (No. 41961029) and "Innovation Star" Program for Outstanding Postgraduates in Gansu Province (2021CXZX-187).

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