The Impact of the Urban Linkage Relations in the Beijing-Tianjin-Hebei Region in the New Era on Economic Development Based on the Gravity Model in the Context of Big Data

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Abstract: This research deeply analyzes the formation mechanism and evolution dimension of the existing linkage relationship by measuring the urban linkage relationship in Beijing-Tianjin-Hebei region. Based on the research of traditional gravity model, the linkage relationship between cities is clearly presented by adopting ArcGIS software drawing tools reasonably, and the issue of urban linkage is studied in China's urban system network. On the premise of the existing formation mechanism and evolution dimension of linkage relationship, through the measurement research of urban linkage relationship, it gradually penetrates into the dimension of coordinated economic development. The main research conclusions drawn are as follows: Beijing, Tianjin and Shijiazhuang, as the three central cities in the Beijing-Tianjin-Hebei economic circle, have a significantly strong effect in promoting the economic development of individual cities within the one-hour economic circle formed by them, which is more prominently after the central cities and individual cities have accessed railways; The linkage relationship between Beijing and Tianjin is characterized by dislocation, which depends on the node index of individual cities instead of distance stratification. For these three central cities Beijing, Tianjin and Shijiazhuang, radiate evenly to hinterland cities in different dimensions and the radiation intensity in Tianjin is characterized by "stronger in the east and weaker in the west". The larger the node index of an individual city, which denotes that it is prone to have a linkage relationship with the central city, this linkage feature is separated from the "strong alliance" at the volume level. In the medium and short distance linkage of Beijing-Tianjin-Hebei region, the blocking effect of spatial distance has changed insignificantly, and the intensity of urban linkage of medium and long distance still presents the trend of distance attenuation. Therefore, the following research enlightenment is drawn as follows: the regional economic development in the new period should not be confined to the economic development at the individual level of the central city, but also pay special attention to the economic spillover effects brought by the urban linkage and other industrial developments. Additionally, the linkage theory should be updated in time while observing the issue of urban linkage in the new era, the dynamic measurement method of urban linkage relationship based on nodes, routes and networks should be constructed and build a research perspective of general balanced coordinated development based on the inter-city flow factors.

Keywords: Linkage; Beijing-Tianjin-Hebei; New period; Measurement; Economic Development

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1 Introduction

Currently, the formulation of China's regional economic policies has changed from the restrictive thinking in the perspective of local equilibrium in the 12th Five-Year Plan period to the market-oriented thinking in the perspective of general equilibrium in the 14th Five-Year Plan period. The connotation of the coordinated development of Beijing-Tianjin-Hebei may also have transformed with the change of policies. From the perspective of local areas, the urban linkage network centered on Beijing, Tianjin and Shijiazhuang carries the coordinated development contents of industrial transfer, ecological expansion, co-construction and sharing, etc. From the overall perspective of China's urban system, Beijing-Tianjin-Hebei region, which as an economically developed region, is one of the significant concentration areas of outflow factors in underdeveloped regions. With the steady advancement of the new urbanization strategy of "people-centered" and the weakening of policy resistance in the cross-regional flow of production factors, the issue of urban linkage in Beijing-Tianjin-Hebei region is becoming increasingly complicated, denoting the re-agglomeration of external factors synchronized with the intra-regional diffusion effect. In the local "14th Five-Year Plan" of the three provincial-level administrative regions of Beijing, Tianjin and Hebei, it can be clearly observed to find that the overall plan of the relationship between time and space, government and market, competition and cooperation, etc. Therefore, the new period that we are concerned about not only refers to the new plan issued at the policy level, but also denotes the new conditions, new environment and stage that China's regional development is encountering, and the new ideas, visions and paradigms forced by this. It must be acknowledged that there are still many ambiguities and shortcomings in the existing research on how to effectively measure the urban linkage relationship in the new period. In terms of the practical problems in Beijing-Tianjin-Hebei region, how to integrate the concept of "people-centered", the goal of coordinated development and the reform concept of breaking the understanding of the subordinate and the resistance of administrative divisions into the framework of the measurement of urban linkage relationship are the critical issues that must be urgently addressed of the urban linkage research in the new period. In this paper, paying attention to "people in flow", the micro carrier of urban linkage is actually focusing on the dimension of inter-city factor flow driven by population flow, abstracting the actual economic relations between cities, and integrating the idea of "people-centered" into the measurement framework. In the sample screening of the research, efforts are made to break the understanding of jurisdiction and the division of administrative divisions, and finally retain the sample of hinterland cities with actual economic ties with the central cities. The research at the regional level is different from the Beijing-Tianjin-Hebei urban agglomeration at the administrative division level.

2 Literature Review

According to a large number of previous literatures on the measurement of urban linkage, most scholars have focused on the design of measurement methods at length, representative researchers like Zhang Gui et al. (2019) [1], Quanbo et al. (2016) [2], Zhao Jinghua et al. (2018) [3] and Zhang Guohua et al. (2014) [4]. The measurement content mainly concentrated on the "direction" and "dimension" of urban linkage (Gong Piming et al., 2020; Wen Fenghua et al., 2017) [5-6]. The construction of the measurement method mainly adopts the experience method

and the introduction of theoretical model method (gravity model, potential model, etc.) (Zhou Wei, 2021; Lu Xiaoli et al., 2021) [7-8], there is no doubt that there are some relatively novel frontier research among them, specifically, Dai Xuezhen conducted a research by comparing the contribution of railway, highway and aviation to the linkage strength of Beijing-Tianjin-Hebei region based on the measurement framework of gravity model and potential model (Dai Xuezhen, 2019) [9]. Hou Heping finally proposed a radiation force measurement method based on short and medium distance accessibility through in-depth research on the linkage relationship of township regions (Hou Heping, 2014) [10]. Yu Siqin measured the coordinated development level of the Yangtze River Delta region through the mixed use of gravity model and coupling degree model (Yu Siqin, 2021) [11]. Chen Yan evaluated the static spatial-temporal pattern and dynamic evolution direction of the tourism industry in the three eastern provinces under the guidance of potential model (Chen Yan, 2019) [12]. Comparatively speaking, the measurement system based on empirical method is more accurate and reasonable, and the measurement results often are in conformity with practical experience. Meanwhile, it also encounters a challenge for scholars in research: the difficult measurement system construction and heavy workload. The measurement system constructed based on the theoretical model method is convenient in operation, but some key logic and index selection seems too abstract, which requires manual correction to eliminate the deviation between the measurement results and practical experience. More specifically, there are some differences between the gravity model and the potential model in terms of measuring ideas. The former is mainly used to analyze and predict spatial flow, while the latter is mainly adopted to solve the issue of interaction force and to reveal the probability of interaction between different groups.

Accessibility indicators are widely applied into the measurement of urban linkage. Specifically, there is linkage relationship between the economic and social level of a given region and other regions, or indicates the possibility of constructing economic and social relations. The measurement research based on spatial accessibility mainly includes Yu Huimin et al. (2020) [13], Jin Cheng et al. (2012) [14], Tian Ye et al. (2018) [15], Ma Lili et al. (2021) [16], Zhao Yun et al. (2015) [17]. Most research on accessibility measurement is on the basis of the centrality of a given particle in a region, which only refers to the accessibility within the region; while simultaneously there is no doubt that there are some relatively novel frontier research among them, Chen Wei introduced spatial heterogeneity into the analysis framework and formed a realistic accessibility index based on the dimensions of continuity and compactness (Chen Wei, 2020) [18]. With the integration of measurement methods and traditional spatial technologies, the development of human geography relied more heavily on the expansion and discovery of new spatial analysis technologies (Li Kangkang, 2020) [19]. With the continuous development of complex network theory in the field of urban linkage, a variety of orderly complexity problems running through urban linkage had been successfully solved. The specific characteristics of the network were identified based on the complex network theory. Chen Xin measured the agglomeration coefficient and average path length of the aviation network by taking the aviation network in the Yangtze River Delta as a sample (Chen Xin, 2020) [20]. Chen Ming adopted GIS spatial analysis method to depict the complex network characteristics of railway passenger transport network, and pointed out the common characteristics and evolution direction of railway network (Chen Ming, 2020) [21]. Under the guidance of static comparison and dynamic evolution, Xu Jia made an in-depth interpretation of the topology of subway network in Beijing (Xu Jia, 2020) [22].

Combined with the existing conditions, environment and stage of China's regional development in the new period, the existing research on urban linkage measurement mainly has the following deficiencies. Initially, taking administrative boundaries as the absolute basis for selecting sample cities ignores the disunity among economic geography center, regional administrative core and factor gathering center under the background of free flow of factors in the new era. Secondly, the root of the urban linkage relationship in the new period lies in the behavior choice of micro-individuals in inter-city flow, while the research based on the measurement framework constructed by western theoretical models cannot reveal the essence of the problem. Thirdly, owing to the limitation of the basic assumptions of the traditional theoretical model, it is difficult to take into account the influence of other cities except the two cities on the linkage relationship when using the measurement method. Therefore, under the background of regional coordination and integration in the new era, it is necessary to discuss the urban linkage relationship in the overall pattern of China's urban system. Fourthly, in the context of regional coordination and integration, China's urban system is gradually turning into an inseparable whole, and the problem of urban linkage has converted into a purely general equilibrium issue, which cannot be simply identified and interpreted by the measurement framework of local equilibrium. On this basis, the paper attempts to introduce the chemical adsorption theory and the complex network theory into the measurement framework. By adopting the chemical adsorption theory to abstract the inter-city factor flow direction and the behavior choice of micro-individuals, the introduction of the complex network theory is conducive to arranging the urban linkage problem into the overall pattern of China's urban system for further discussion, and it can give consideration to both the accessibility problem in geography and the general equilibrium problem in economics.

3 Design on Research Samples and Measurement Methods

3.1 Research samples and data acquisition

To characterize the urban linkage characteristics of Beijing-Tianjin-Hebei region based on railway passenger transport links, the geographic scope of this research basically covers all the one-hour economic circle, with five cities of Chifeng, Qinhuangdao, Jinan, Taiyuan and Ulanchabu as reference points. The sample selection breaks the understanding of administrative jurisdiction, and eliminates county-level cities and districts within the one-hour economic circle that have no actual economic connection with Beijing, Tianjin, and Shijiazhuang based on the calculation results of the "linkage index", with 74 county-level cities and districts remaining. The data on the train number of urban passenger used in the research comes from the "12306" website and amended with reference to the data from "Qunar.com", which queried from September 20 to September 30, 2021. The data query starts from the three cities of Beijing, Tianjin, and Shijiazhuang, and ends with the individual sample cities. All train types and train numbers are counted. For detailed statistics and calculation methods, please refer to the "Linkage Index" construction method. The longitude and latitude data sources of the sample cities are extracted from Baidu map, and the city volume data is extracted from the government work report. The sample cities included in the study are shown in Figure 1.

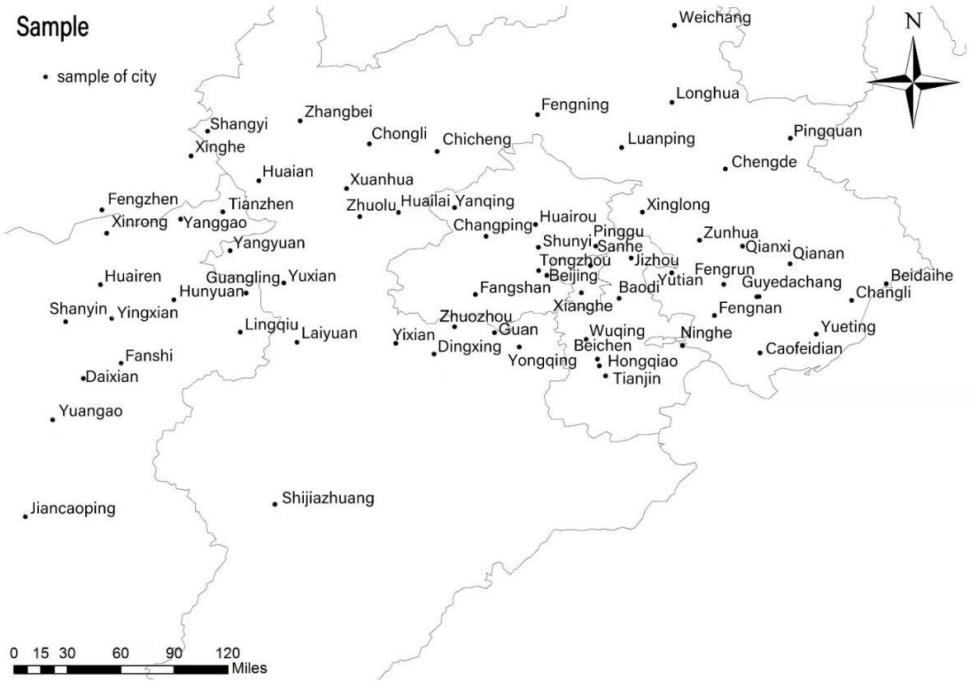

Fig. 1 Distribution of sample cities

Note: The distribution map of the sample cities is drawn by the researcher via ArcGIS software. Each sample point represents a sample city, and areas with dense sample points are only marked with the name of the main city, and the three cities of Beijing, Tianjin and Shijiazhuang are used as location references.

3.2 Theory construction

At present, scholars have built a more complete measurement system to achieve an effective measurement on the linkage relationship among cities in different regions according to the chemical adsorption theory. In the urban spatial interaction network, individual cities are like adsorbents in chemical concepts. As for the population, capital, technology, and data flowing between cities, they are like chemical molecules governed by adsorption. Therefore, the dynamic adsorption process explained by the chemical adsorption theory can more completely and abstractly describe the spatial allocation mechanism of the inter-city elements freely flowing according to economic laws. The construction traffic network between cities may accelerate the concentration of elements from hinterland cities to central cities, as well as cause some elements to spread from central cities to peripheral areas. In fact, the necessity of introducing chemical adsorption theory into the measurement framework of urban linkage relationship lies in the fact that the actual meaning of the urban linkage in the new era is that the economic connection between cities is rooted in the market mechanism between cities and the flow of factors. In essence, it is the microscopic individual behavior selection and the macroscopic characteristics it exhibits. The traditional theoretical model is rooted in the theory of new economic geography. Its initial construction process is relatively macro, and the calculation of urban linkage relationship based on traditional theoretical model has been difficult to cover various contents

of urban linkage. In order to solve the problem of vacuity and deviation from reality in the calculation results of linkage relationship, it is necessary to use the factor flow between cities and micro-individual behavior selection as the theoretical foundation to construct a measurement model of the linkage dimension of local cities under the guidance of the new policy. The chemisorption theory not only provides a reference for the measurement of the element agglomeration dimension at the micro level, but also covers the causal interaction between element agglomeration and urban expansion. The Gibbs formula explains the relationship between the surface concentration of the solution, the internal concentration and the surface tension of the solution. Assuming that the isothermal conditions are met, the calculation formula of solute adsorption per unit area in the dissolved surface layer is:

$$\Gamma_2 = -\frac{a_2}{RT}\frac{d\gamma}{da_2} \tag{1}$$

In the above formula, γ represents the surface tension of the solution, and its rate of change is the derivative dγ/da2 of the solute activity a2. In the Gibbs formula, there are three cases of solution adsorption under isothermal conditions: First, if Γ>0, it indicates that the solute on the surface of the solution is positively adsorbed, and the concentration of surface solute is higher than the concentration inside the solution; second, if Γ<0, it indicates that the solute on the surface of the solution is adsorbed negatively, and the concentration of the surface solution is lower than the concentration inside the solution; Third, if Γ=0, a relatively stable state is reached between the surface layer of the solution and the inside of the solution, and adsorption does not occur.

Few researches can accurately describe the dynamic linkage relationship between cities among the existing literature. Thanks to the development of complex network theory, it provides a possible method for dealing with orderly complexity problems. In fact, whether it is a social network or a complex network, its essential problem can be attributed to identification and sorting of important nodes. The existing processing method is generally the distance matrix method of the graph, that is, the elimination method of fusing the secondary node in the model is by establishing the measurement model of the node. The more representative technology is statistical process control technology, and the key nodes must satisfy the following two assumptions: First, the start node and end node of the network plan must be key nodes; second, take the key node as the completion node's work. In the adjacency list of key routes, a singly linked list of lead nodes is established on each vertex, with all the lead nodes forming an array. The nodes in the singly linked list represent the edges attached to the vertices. Although existing algorithms require strict assumptions, if we do not pay attention to the inherent logic of algorithm design. It can be found that the existing railway network can meet the basic assumptions of the algorithm. Taking the cities at both ends of the railway line as the key node and the railway line as the key task, with the help of "naturally formed" data sets, it reflects the key cities, key connections, the symbiotic relationship between cities and the law of urban linkage.

3.3 Measuring and calculating method of urban linkage relationship

With reference to the construction methods of existing research adsorption index and dependency index [23-24] (Zhou Jingxiang, 2015; Wang Chunyang and Zhou Jingxiang, 2016), this research constructs a method for measuring the linkage relationship between cities (linkage index) and the importance of individual cities in the linkage network (node index), weights the

original nodes of the original departure, crossing, and end to the three types of trains, and revises it to the route weight. The measuring and calculating method of the linkage (spatial interaction force) index between cities is designed as:

$$Interaction_{ij} = \frac{1}{\sum_{k=1}^{n} n}(\eta_1 \sum_{k=1}^{6} X_{ij} * k + \eta_2 \sum_{k=1}^{6} Y_{ij} * k + \eta_3 \sum_{k=1}^{6} Z_{ij} * k) \quad (2)$$

Among them, X_{ij} represents the number of train on the key route between city i and city j. The train departs from city i, and the final destination is city j. Yij is the number of Class III passing cars between cities (including the number of cars starting from city i and passing through city j; the number of trains passing from city i to city j; the number of trains passing through city i and city j at the same time); Zij is the number of trains finally arriving at city j (including the trains departing from city i and finally arriving at city j; the number of trains passing from city i to city j). k is the weighting of train types, including 6 types of statistics such as high-speed rail, high-speed trains, and intercity trains, with values ranging from 1 to 6, reflecting the efficiency and cost of factor flow between cities. 1,2 and 3 are the weighted weights of three types of vehicle number X, Y and Z respectively, which can refer to the original weights of adsorption and attachment indexes in existing literatures, and the weights reflect the importance of vehicle number.

The node index reflects the relative importance of individual cities in the urban linkage network. Individual cities can be used to sum up the "linkage index" of all other cities j in the region. The calculation method of node index is:

$$Node_i = \frac{1}{\sum_{k=1}^{n} n}(\sum_{1}^{j} Interaction_{ij}) \quad (3)$$

3.4 Measurement model

This study constructs the measurement model of the urban linkage relationship in the Beijing-Tianjin-Hebei region based on the urban gravity model. On the basis of the traditional gravity model, the problem of urban linkage is placed in the Chinese urban system network via the combination of empirical experience, the relevant variables of urban network characteristics are introduced, including the including the influence of other cities on the linkage relationship between the two cities, and the status of individual cities in the urban linkage network. From the theory, combined with the introduction of empirical variables, try to propose a new understanding and improvement concept of theoretical models in the urban linkage problem in the new era. The formula of the traditional gravity model is:

$$T_{ij} = \frac{KP_i^{\alpha} \cdot P_j^{\beta}}{D_{ij}^{\lambda}} \quad (4)$$

In the above formula, the size of urban space interaction force is represented by Tij, which is determined by two types of factors. One is the variable of the volume nature of individual cities, and the other is the variable of the spatial distance between two cities. The general formula of urban gravity model is:

$$T_{ij} = f(V_i, W_j, S_{ij}) \quad (5)$$

In the above formula, V_i, W_j and S_{ij} represent variables with starting point, ending point and spatial properties, respectively. The empirical logic of this study is actually a more accurate

method to measure the linkage relationship Tij between cities based on adsorption theory and network theory to re-identify and evaluate the impact of traditional variables and new empirical variables on urban linkage relationship and build an econometric model based on gravity model.

$$Interaction_{i_k} = \alpha + \beta_1 space\_k_i + \beta_2 Node_i + \beta_3 eco_i + \phi X + \varepsilon_i \quad (6)$$

Where, $Interaction_{i_k}$ is the linkage relationship between the two cities, namely, the spatial interaction force. $space\_k_i$ represents the spatial distance between the sample city and the three central cities of Beijing, Tianjin and Shijiazhuang; $Node_i$ stands for node index, which reflects the importance of individual cities in the local city linkage network, covering other factors such as actual economic connection, accessibility, location, etc. eco_i refers the economic volume of an individual city, replaced by the GDP of the individual city in 2020; X represents other control variables, representing east-west deviation degree (we), north-south deviation degree (sn) in this study, and linkage intensity of other central cities in the sample cities, which are reflected by urban longitude, latitude and linkage index. ε_i is the random disturbance term. In the econometric model, in addition to the two variables of city volume and spatial distance, the researcher also introduced the relationship between the sample city and other central cities, longitude and latitude, as well as node index according to empirical experience. Statistical description of variables is shown in Table 1.

Table 1 Statistical Description Table of Variables

variable	sample capacity	mean	SD	min. value	max. value
inter_bj	74	42.37	64.32	0	309.35
inter_tj	74	49	140.26	0	936.63
inter_sjz	74	36.02	87.77	0	445.5
we	74	116.05	1.85	112.49	119.48
sn	74	39.86	0.95	36.95	41.94
net	74	694.79	1375.6	2	695.4
eco	74	282.36	333.53	17.59	1873.7
space_bj	74	170.83	90.96	0.82	409.64
space_tj	74	186.01	117.08	0.91	461.06
space_sjz	74	294.59	89.85	148.53	514.09

4 Empirical Results and Explanations

4.1Measurement of linkage relationship between cities

According to the city linkage relationship map, it can be seen that a linkage relationship network has been formed with Beijing as the center. Cities linked with Beijing spread throughout the whole one-hour economic circle, and the number of cities with higher linkage strength and cities with lower linkage strength is evenly distributed. Cities with linkage relationship with Tianjin are mainly in the north of Tianjin, and there are fewer cities with greater linkage strength and they are all located around Beijing. The two most obvious cities are Tianjin and Pinggu. Similarly, compared to Beijing and Tianjin, Shijiazhuang is located to the south, not in the center

of the one-hour economic circle. Therefore, the cities with greater linkage strength with Shijiazhuang are also the two cities around Beijing, Changping and Pinggu, and the linkage strength with other cities that have linkage relationships is also relatively small. The three central cities of Beijing, Tianjin, and Shijiazhuang have urban linkage relationships with many hinterland cities in the one-hour economic circle via comparison. However, there are more cities with relatively large linkages with Beijing and distributed in all directions, while cities with relatively large linkages with Tianjin and Shijiazhuang are mainly concentrated around Beijing. The similarity of these three cities is that the strength of linkage may weaken as the distance from the central city increases.

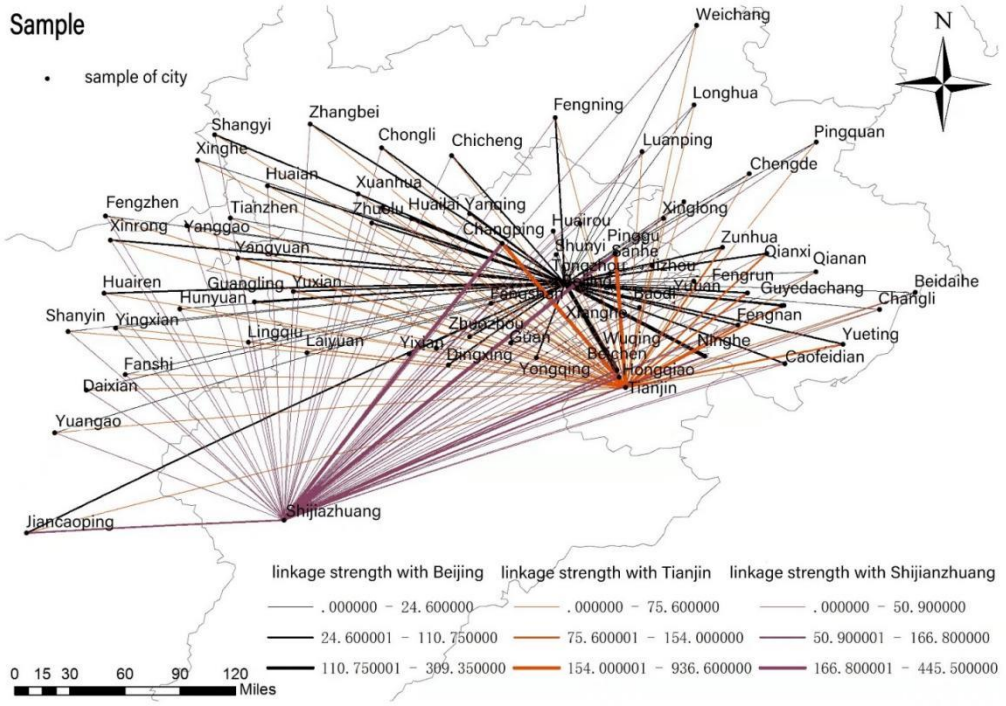

Fig. 2 Linkage relationship between cities

Note: The city linkage diagram was drawn by researchers using ArcGIS software. The thickness of the line segment in the figure represents the size of the "linkage index" between two cities.

4.2 Measurement results and explanations

Based on the framework of the theoretical model (gravity model) of this study that measures the linkage relationship between the two cities, the linkage relationship between hinterland cities and other central cities is introduced as an explanatory variable. The implication of variable introduction is that it is assumed that the linkage relationship between the sample city and the central city is affected by the radiation forces of other central cities. In models 1 to 5, the linkage between hinterland cities and central cities is affected by other central cities. According to Model 1 and Model 2, Beijing and Tianjin may have a cooperative relationship, while Tianjin and Shijiazhuang are positively correlated and may have a competitive relationship. There may

be a stratified dislocation in the hinterland between Beijing and Tianjin. In general, each central city has its relatively fixed hinterland city and fixed radiation range. According to the measurement results of spatial measurement variables and node index variables in Model 1-3, this hierarchical dislocation may not be based on distance division, but based on node index, that is, the status of individual cities in the urban linkage network.

The study introduces the deviation of the latitude and longitude of the sample cities from the geographic center of the region as an explanatory variable, with the meaning implication that the linkage relationship between the three central cities and hinterland cities in the Beijing-Tianjin-Hebei region may have spatial differentiation characteristics in different directions. According to the overall measurement results, the radiation power of individual cities by the central city is relatively even towards the east, west, south, and north directions, which may mean that the sample area lacks industrial belts along the route, or may be because the sample area lacks sub-central cities. It should be noted that the longitude variable is positively significant in Model 2, indicating that the strength of the linkage between the sample cities and Tianjin shows a trend of "strong in the east and weak in the west", which may be related to the competitive relationship between Beijing and Tianjin, and may also be affected by the location of the sample cities.

The implication of introducing urban economic volume indicators and node indexes as explanatory variables is that the mechanism of urban linkage in the Beijing-Tianjin-Hebei region may have changed in the new period. The measurement results show that, generally speaking, the node index, that is, the relative importance of the city in the linkage network, is significantly positively correlated with the city linkage relationship. In addition, the urban linkage has been separated from the original volume, which does not mean that the greater the economy, the urban linkage must occur. There is no complete correspondence between the two. The insignificance of GDP just provides the possibility for the accessibility of individual cities and the tendency of cities with more developed transportation facilities to connect with central cities, and improves the level of accessibility of a city or to increase the importance of the role played in the urban linkage network may have a significant effect on the development of the city. It should be noted that the significant negative correlation presented by the node index in Model 2 may be affected by the competition and cooperation of central cities and the hierarchical dislocation of hinterland cities, which is consistent with the above analysis of competition and cooperation of central cities.

In the measurement results of the spatial distance variable, the three cities of Beijing, Tianjin, and Shijiazhuang are relatively close in spatial distance, so the spatial distance variable is not significant. The pure spatial distance in the traditional sense may have been weakened, and the determinant of urban linkage may have been transformed into the broader commuting cost between cities. This weakening result may be related to the radiation intensity of the central city, the coordination of regional development, as well as the developed transportation network. According to the measurement results, the spatial differentiation of radiation intensity between Beijing and Tianjin is relatively high. With the median distance as the standard, half of the sample cities that are closer to the central city (Beijing, Tianjin) are tried to be eliminated. It is concluded that the spatial distance exhibits significant characteristics, and the distance attenuation trend of urban linkage is still obvious.

Table 2 Measurement Result

	Model 1	Model 2	Model 3	Model 4	Model 5
variable	inter_bj	inter_tj	inter_sjz	inter_bj	inter_tj
inter_bj		-0.197	-0.005		-0.284
		(0.121)	(0.062)		(0.198)
inter_tj	-0.201*		0.450***	-0.813***	
	(0.120)		(0.028)	(0.273)	
inter_sjz	-0.014	1.755***		0.115	0.582***
	(0.242)	(0.111)		(0.280)	(0.202)
we	-1.751	9.248*	-2.718	1.842	-7.790
	(3.802)	(5.432)	(3.142)	(4.255)	(5.892)
sn	1.895	3.589	2.313	-7.068	-6.205
	(8.485)	(7.483)	(5.488)	(8.142)	(7.241)
node	0.035***	-0.028***	0.025***	0.056***	0.039***
	(0.008)	(0.008)	(0.003)	(0.013)	(0.014)
eco	0.01	0.011	0.005	-0.010	-0.001
	(0.021)	(0.022)	(0.010)	(0.059)	(0.030)
space_bj	-0.101			-0.188*	
	(0.087)			(0.107)	
space_tj		0.022			-0.400***
		(0.096)			(0.138)
space_sjz			-0.064		
			(0.077)		
constant	168.400	-1,210	237.600	138.900	1,2620
	(544.300)	(729.200)	(494.800)	(522.600)	(810.200)
sample capacity	74	74	74	36	36
GFI	0.423	0.878	0.921	0.490	0.900

Note: *, ** and *** correspond to being significant at the level of 10%, 5% and 1%; the numbers in brackets represent the standard error.

5 Conclusion

This study measured the linkage relationship between the three central cities, Beijing, Tianjin and Shijiazhuang, and hinterland cities, and identified the formation mechanism and evolutionary direction of the urban linkage relationship network in the Beijing-Tianjin-Hebei region. The main conclusions of the study are as follows: firstly, at the level of urban linkage, there is still a significant cooperative relationship between the two central cities of Beijing and Tianjin; there is a competitive relationship between Tianjin and Shijiazhuang; and there is no obvious competitive and cooperative relationship between Beijing and Shijiazhuang. Second, the radiation ranges of the two central cities of Beijing and Tianjin have dislocation characteristics, which may not depend on the distance, but on the importance of individual cities in the regional city network. Generally speaking, cities with strong importance are more likely to have a linkage relationship with Beijing. Third, the radiation power of the central cities on

the hinterland cities is evenly distributed in the Beijing-Tianjin-Hebei region towards different directions, and only the radiation power of Tianjin to the hinterland cities presents an obvious characteristic of "strong in the east and weak in the west". Fourth, the influence path of the traditional economic volume factor on the urban linkage relationship may have changed. The urban linkage relationship in the Beijing-Tianjin-Hebei region has deviated from the traditional "powerful combination". Generally speaking, cities with a larger node index are more likely to build economic links with central cities. Fifth, the effect of spatial distance on urban linkage with short and medium distance has been weakened in the Beijing-Tianjin-Hebei region. However, the distance attenuation trend is still obvious for the linkage of cities with longer distances.

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