Comparative Analysis of city connection network Based on Gravity Model and Baidu Index in Wuhan urban agglomeration

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Abstract. From the perspective of economic flow and information flow respectively, this paper applies gravity model and Baidu index method to study the city connection of Wuhan urban agglomeration and makes a comparative analysis. The result shows that the characteristics of cities in Wuhan urban agglomeration are different in economic connection network and information connection network. Based on the differences between the two types of spatial networks in Wuhan urban agglomeration, the connection ratio difference of each city in the two types of models is calculated. And the cities in the urban agglomeration are classified into economic flow dominance city, information flow dominance city or balanced flow city.

1. Introduction
With the rapid advancement of economic globalization and regional integration, urban agglomeration, as a dynamic region in the regional development space, forms a city network with frequent flow of all elements within its scope.[1] The stream of various elementary flows strengthens the links between cities. Many scholars in China studied the urban connection and its network characteristics from the angle of element flow. Xiong Lifang et al. used Baidu index to study the characteristics of an urban network structure from the view of information flow in the Yangtze River delta, Pearl River delta and Beijing-Tianjin-Hebei region.[2] ZhouXiu et al. measured and analyzed the spatial connections among cities in the urban agglomeration of the middle reaches of the Yangtze River by using the data of inter-city highway and railway passenger traffic flow.[3] These researches mainly analyzed urban connections and its network structural characteristics from a single perspective. There is no comparative analysis of urban network structural characteristics based on different element flows. This paper measures the city connection of Wuhan urban agglomeration from the view of economic flow or information flow. The strength of economic connection between cities is surveyed by Gravity model. The information connection between cities is calculated with Baidu search index. Comparing the characteristics of urban connection network based on different element flows is conducive to recognizing the position of each city in different element networks in Wuhan urban agglomeration. The Comparative analysis also contributes to reasonably acquainting the characteristics of cities in Wuhan urban agglomeration, so as to promote the coordinated development of cities in Wuhan urban agglomeration.

2. Urban economic relation of Wuhan urban agglomeration based on gravity model

2.1. Measurement of the strength of economic ties
The intensity of economic ties is an index used to measure the degree of economic ties between regions. Gravity model is often applied to calculate the strength of economic ties. In the gravity model, the gravity value between cities represents the strength of regional economic connection or the size of spatial interaction, which comprehensively reflects the city’s ability to radiate external economy. Gravity model is a basic method that uses panel data to describe the economic flow between urban clusters. In this paper, the GDP, population, total social investment in fixed assets, total retail sales of consumer goods, and road distance of each city from the Hubei Statistical Yearbook in 2017 are selected to estimate the strength of economic connection among cities in Wuhan urban agglomeration. Then the level of urban network connection is divided. The formula for calculating the strength of economic connection is as follows.

\[ L_{ij} = \frac{G_i \times P_i \times I_i \times S_i \times G_j \times P_j \times I_j \times S_j}{D_{ij}}, \quad (i \neq j) \]  

(1)

\[ L_i = \sum_{j=1}^{n} L_{ij}, \quad (i \neq j) \]  

(2)

In the formula, \( L_{ij} \) is the intensity of economic connection between city i and j; \( G_i \) and \( G_j \) are the GDP of cities i and j respectively. \( P_i \) and \( P_j \) are the permanent residents of cities i and j respectively. \( I_i \) and \( I_j \) are the total fixed asset investment of cities i and j. \( S_i \) and \( S_j \) represent the total retail sales of consumer goods in cities i and j; \( D_{ij} \) is the shortest highway distance from city i to downtown j. \( L_i \) represents the total amount of economic connection in city i.

2.2. Analysis of economic connection results

In accordance with the measured intensity of economic connection between cities, combining the research results of predecessors, the strength of economic connection between cities are divided into four degrees: strong connection, relatively strong connection, relatively weak connection and weak connection. On the basis of the total gravity value of each city, cities are divided into four levels. Figure 1 demonstrates the spatial distribution of the economic linkage of Wuhan urban agglomeration in 2017 with ArcGIS software.

![Figure 1. economic connection network of Wuhan urban agglomeration](image)

On the whole, Wuhan, Huanggang and Ezhou form a triangular network structure, and the economic ties among the three cities are strong. The economic ties of the eastern cities are stronger than those of the western cities. From the strength of a single link, the economic connection between Ezhou and Huanggang is the strongest. Wuhan also has a strong economic connection with Xiaogan and
Huanggang, while Wuhan has a weak economic connection with Tianmen, Qianjiang and Xiantao in the west. Based on the total value of gravity of a city relative to other cities, the cities are divided into four levels by the natural discontinuity method. The results are shown in Table 1. The first level includes Wuhan and Huanggang, which highlights Wuhan's central position and excellent achievements of Huanggang's social and economic development. The total gravity value of Huanggang is high. On the one hand, Wuhan's city quality is large, which leads to strong economic tie between Wuhan and Huanggang. On the other hand, because of the short distance between Ezhou and Huanggang, the economic relationship between Ezhou and Huanggang is very strong. The second level contains Xiaogan and Ezhou. The third level embodies Huangshi. And the fourth level involves Xianning, Tianmen Qianjiang and Xiantao, indicating that economic ties between cities in the fourth level are weak.

Table 1. Hierarchical distribution of Wuhan urban agglomeration network based on two models

| The city level | Gravity model network | Baidu index network |
|----------------|-----------------------|---------------------|
| The first level | Wuhan, Huanggang      | Wuhan               |
| The second level | Xiaogan, Ezhou        | Xiaogan, Huanggang, Ezhou, Huangshi, Xianning |
| The third level | Huangshi              | Qianjiang, Xiantao  |
| The fourth level | Xianning, Qianjiang, Tianmen, Xiantao | Tianmen             |

3. Information connection of Wuhan city group based on Baidu index

3.1. Measurement of information connection intensity

With the rapid development of information society, especially in Big Data Era, anyone can search and pay attention to another place at any location. Baidu Index is a method to describe the information flow between urban agglomerations in Big Data Era. Based on the search volume of residents of one city to another, Baidu index can accurately reflect the information connection between cities and display the radiation and exchange ability of urban information. The overall daily average of the user search index in 2017 is selected as the research data in this study. The information link intensity between cities is computed through the Baidu search index between cities to analyze the regional information link network characteristics. The calculation formula of information connection intensity is as follows:

\[ R_{ij} = C_{ij} \times C_{ji}, \quad (i \neq j) \]  
\[ R_i = \sum_{j=1}^{n} R_{ij}, \quad (i \neq j) \]  

In the formula, \( R_{ij} \) is the strength of information connection between city i and city j; \( C_{ij} \) represents the information attention of city i to city j; \( C_{ji} \) represents the information attention of city j to city i; \( R_i \) represents the total amount of information contact in city i.

3.2. Analysis of information connection results

The spatial distribution of urban information connection in Wuhan urban agglomeration is drawn in Figure 2.
Figure 2 demonstrates that Wuhan has powerful information links with other cities, indicating that Wuhan is the information center of the urban agglomeration. Compared with the gravity model, Wuhan's central position is more obvious. From a single link, the information link between Wuhan and Xiaogan is the strongest. Wuhan and Huangshi, Huanggang, Ezhou and Xianning are also closely linked. There is a great spatial discrepancy in the information connection between cities, and the information links between eastern cities and western cities are weak.

4. Comparative analysis of urban network based on two models

Through the above comparative analysis, Wuhan is at the core in these two models. Regardless of the total value of information contact or the total gravitational value of the city, Wuhan ranks first in the region and presents a unique situation in the urban agglomeration. As the central city of urban agglomeration, Wuhan has a strong connection with the eastern city of urban agglomeration. However, Wuhan's economic links with western cities are relatively weak, which indicates that Wuhan, as a core city, has limited economic radiation ability. The ratio difference P of each city in the two types of networks is calculated in order to better express the differences between cities of Wuhan urban agglomeration in the two types of spatial networks (shown in Table 2). If the absolute value of the ration P of a city is not less than 0.1, the performance of the city in the two models is considered to be significantly different. Based on this method, the cities of Wuhan urban agglomeration are divided into three categories. The first category, named as information flow dominance city, has high popularity in the virtual network, but limited economic radiation capacity to surrounding cities, which includes Wuhan. The second category is called economic flow dominance city with strong influence on the regional economy but relatively weak information influence. Economic flow dominance city has a strong radiating effect in the real economy, and is often the development pole or core of the regional real economy, such as Huanggang and Ezhou. The third category is named balanced flow city with similar economic and information impacts in two types of spatial networks, such as Xiaogan, Huangshi, Xianning, Xiantao, Qianjiang and Tianmen.
Table 2. Proportion and ranking of urban connections in Wuhan urban agglomeration based on two network models

| city     | gravity model | Baidu index | The difference of the proportion P=i-j |
|----------|---------------|-------------|---------------------------------------|
|          | Total strength of economic ties | Proportion i | rank | Total strength of information ties | Proportion j | rank |                  |
| Wuhan    | 4650.33       | 0.28        | 1    | 646749          | 0.42        | 1    | -0.13             |
| Huangshi | 1466.23       | 0.09        | 5    | 123170          | 0.08        | 4    | 0.01              |
| Ezhou    | 2867.39       | 0.18        | 3    | 120778          | 0.08        | 6    | 0.10              |
| Xiaogan  | 2059.20       | 0.13        | 4    | 183502          | 0.12        | 2    | 0.01              |
| Huanggang| 3961.94       | 0.24        | 2    | 140114          | 0.09        | 3    | -0.15             |
| Xianning | 631.42        | 0.04        | 6    | 121701          | 0.08        | 5    | -0.04             |
| Xiantao  | 319.14        | 0.02        | 7    | 84564           | 0.05        | 7    | -0.03             |
| Qianjiang| 163.10        | 0.01        | 9    | 72475           | 0.05        | 8    | -0.04             |
| Tianmen  | 221.83        | 0.01        | 8    | 59349           | 0.04        | 9    | -0.02             |

5. Conclusion

By comparing the urban network of Wuhan urban agglomeration described by gravity model economic flow and Baidu index information flow, this paper draws the following conclusions: (1) the two networks portray the urban connection of Wuhan urban agglomeration from different flow perspectives, displaying different spatial distribution characteristics. (2) Based on the ratio difference between cities in the two models, the cities in the Wuhan urban agglomeration are classified into economic flow dominance city, information flow dominance city and balanced flow city. The results are helpful to reasonably understand the characteristics of urban connection and urban network structure in Wuhan urban agglomeration, so as to provide suggestions for the positioning and development of cities in the urban agglomeration. The urban connections between city clusters are complex and diverse, and more models are needed to comprehensively depict the connections between Wuhan urban agglomeration.

Acknowledgments

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