



Analysis of Spatial Interaction in Taiyuan Suburbs Based on Gravity Model

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Abstract. Gravity model is a common model to measure the interaction force between two places in space. Firstly, this paper selects several indexes to measure the regional quality according to previous studies, evaluates the comprehensive quality of the two places, at the same time, the weight, speed and monetary cost of various transportation modes between the two places are used to express the usual distance, and a new expression of gravity model is constructed. Then, taking Taiyuan City as an example, the new expression is used to calculate the spatial interaction force between Taiyuan city and the subdistricts and counties, and finally the suggestion is put forward to promote the interaction between the city and the suburbs.

Keywords: Gravitational models · space interactions

1 Introduction

Since the planning of Taiyuan metropolitan area, the government has supplemented it many times, and the planning scope has been expanding. Taiyuan Metropolitan Area is to further promote the development of the city, in order to implement the spirit of the 11th Provincial Party Congress, give full play to the central leading role of Taiyuan Metropolitan Area in innovation driving, transformation and upgrading of the province, accelerate the construction of Shanxi transformation and comprehensive reform demonstration zone and Shanxi agricultural Valley, and enhance the status of the provincial capital, Taiyuan Metropolitan area planning, according to the provincial urbanization strategic arrangement of “one core, one circle and three clusters”.

At present, the planning scope of Taiyuan metropolitan area is: Taiyuan City six districts, Qingxu County and Yangqu County, Jinzhong City Yuci District, Taigu County administrative jurisdiction, an area of 6503 square kilometers, will create the urban space structure of “twin cities and multiple groups”, among which, “twin cities” refers to two central urban areas, including Taiyuan main urban area and Taiyuan - Jinzhong co-construction area. “Multi-group” refers to the integration of Yangqu, Nitun, Qingxu, Xugou, Xigu, Xiwen and other six industrial and urban clusters.

The former metropolitan area will achieve a successful transformation of resource-based economy, build an independent innovation base of new energy and an emerging

industry base with international influence, realize the integration of urban and rural areas, fundamentally reverse the spatial structure of single center, embark on the track of sound development of urban and rural ecological system, fundamentally improve environmental quality, and significantly enhance comprehensive competitiveness, cultural influence and radiation driving force. People's living standards have improved significantly. For the construction and development of Taiyuan metropolitan area, the interaction between Taiyuan urban and suburban space is an important part that cannot be ignored.

2 Gravity Model

Gravity model, also known as gravity model, originated in the 19th century. It is a model constructed according to the distance decay principle and Newton's universal gravitation formula, which is used to measure the interaction force between two regions.

Gravity model is a widely used model of spatial interaction. It is a mathematical equation used to analyze and predict the form of spatial interaction. It has been constantly expanded and applied in many research fields, such as studying spatial layout, tourism, trade and population migration, and has obtained a lot of useful research results.

The expression of gravity model is:

In fact, many studies have noticed the importance of regional comprehensive quality assessment, that is, to establish a regional quality assessment index system, and finally use the regional comprehensive quality index K to replace a single index of regional quality M .

Based on Wu Dianyan's (2004) gravitational model, the following formula is derived [4]:

$$I_{ij} = \frac{M_i M_j}{d_{ij}^b} = \frac{K_i K_j}{\sum_{i=1}^n \lambda_{ij} C_{ij} T_{ij}} \quad (1)$$

Among them: I_{ij} is the space interaction force between ground i and ground j ; M_i and M_j are the mass of ground i and ground j respectively; d_{ij} is the distance between ground i and ground j ; b is a constant. λ_{ij} represents the weight of the i -th mode of transport between place i and place j , C_{ij} represents the monetary cost of the i -th mode of transport between place i and place j , and T_{ij} represents the time cost of the i -th mode of transport between place i and place j .

Another important issue in the basic gravity model is the choice of distance index b . Theoretically, b should be equal to 1 or 2, but empirical studies show that the value of b can change within the range [5, 30]. The reason lies in long-distance transportation and the different transportability of different goods, thus affecting the value of b (Wu Dianting, 2004). b is equal to 2 [4].

3 Suburban Definition

Any city is made up of urban and suburban areas. In ancient times, the inner part of the "town" was the city and the outer part was the suburb. Now, the urban area generally refers to the areas engaged in non-agricultural industries and closely connected with each other in the city, and the rest is the suburb (Yan Yiping, 2004) (Wei Houkai, 2006) [1, 2].



Fig. 1. Suburban Layout of Taiyuan City

Based on this, Taiyuan City under the jurisdiction of counties, cities, districts, a total of 10. Among them, Xiaodian District, Yingze District, Xinghualing District, Jiancao District and Wanbolin District have a high population density, the sum of the secondary and tertiary industries accounts for more than 95%, and the non-agricultural level is the highest. Fourth, they are closely connected in terms of regional space and industrial structure, so they are defined as urban areas.

Draw the urban and suburban layout of Taiyuan City in Fig. 1.

4 Measurement of Gravity in Suburban Areas

The calculation of the interaction force between urban and suburban space in Taiyuan is mainly divided into two parts:

- (1) Calculation of the comprehensive mass K (molecular calculation) of Taiyuan urban area and subdistricts and counties;
- (2) Deepening of the connotation of distance between urban and suburban districts and counties (calculation of denominator) [5–10].

4.1 Comprehensive Quality K -Principal Component Analysis

- (1) Selection index

In the evaluation of the comprehensive quality index of urban and suburban areas of Taiyuan City, the selection of indicators follows the following principles: they must be factors within their respective regions; Factors that must be able to influence spatial interactions between regions; The principle of easy receipt of data. According to the above

Table 1. Eigenvalue and principal component contribution rate

Principal component	①	②	③
Registered population (Ten thousand people)	4.362	0.6231	0.6231
Per capita GDP (ten thousand Yuan)	1.297	0.1854	0.8084
The output value of the primary industry (ten thousand Yuan)	0.844	0.1205	0.9290
Output value of the secondary industry (ten thousand Yuan)	0.358	0.0512	0.9801
Output value of the tertiary industry (ten thousand Yuan)	0.124	0.0177	0.9978
Total industrial output value above designated size (ten thousand Yuan)	0.014	0.0020	0.9998
Total retail sales of consumer goods (ten thousand Yuan)	0.002	0.0002	1.0000

principles, we selected eight indicators, including registered population (10,000), per capita gross domestic product (10,000), with specific data from 2021 Taiyuan Statistical Yearbook.

- (2) Dimensionless processing of index original data
- (3) Principal component analysis

Input standardized data into SPSS software for calculation, and the calculated results are shown in Table 1.

Among them: ①②③ respectively represent: Eigenvalue, Variance contribution rate and Cumulative variance contribution rate.

As can be seen from Table 1, the eigenvalue of the first principal component is 4.362, the variance contribution rate is 62.31%, and the cumulative variance contribution rate of the first four principal components is 98.01%, which indicates that the values of the first four principal components can fully represent the changes of the above seven original variables.

- (4) Determine the weight

$$w_n = \mu_n \left(\sum_{i=1}^4 \mu_i \right)^{-1} \tag{2}$$

Among them: $n = 1, 2, 3, 4$; μ_i is the corresponding eigenvalue.

Calculation result: $w_1 = 0.6358, w_2 = 0.1890, w_3 = 0.1230, w_4 = 0.052$.

- (5) Calculate the suburban comprehensive quality index K of Taiyuan

According to the weight and principal component load matrix, using the formula, the calculation results are shown in Table 2.

Data description: Since the calculation result of the comprehensive score is negative, it is not conducive to the following calculation. Therefore, “+1” (linear translation) is performed on the basis of the comprehensive score to make all K values positive.

Table 2. Results of comprehensive quality evaluation of Taiyuan urban and suburban counties

Area	Composite scores(x)	x + 1	Area	Composite scores(x)	x + 1
urban	1.4765	2.4765	Yingze	-0.1800	0.8200
Xiaodian	1.1592	2.1592	Xinghualing	-0.2525	0.7475
Qingxu	0.8170	1.8170	Jinyuan	-0.5566	0.4434
Jiancaopin	0.7113	1.7113	Gujiao	-0.6563	0.3437
Wanbailin	-0.0805	0.9195	Loufan	-0.8135	0.1865
Yangqu	-0.1481	0.8519		-0.1800	0.8200

4.2 Deepening of the Connotation of Distance Between Districts and Suburban Counties

Deepening the connotation of distance between urban and suburban districts and counties. Based on the transportation modes from urban to suburban areas of Taiyuan City, the weight, speed and monetary cost of different transportation modes are assumed as follows (Table 3 and Table 4):

(1) Combination of different modes of transport

① $\lambda = 1$ when there is only one transportation mode from urban area to suburban area; When there are two modes of transportation from urban area to suburban area and county, $\lambda_1 = 09$ (general road), $\lambda_2 = 01$ (railway); $\lambda_1 = 03$ (general road), $\lambda_2 = 06$ (expressway), $\lambda_3 = 01$ (railway) when there are three modes of transportation from urban area to suburban area: general road, expressway and railway.

② The average speed of road transportation from urban areas to suburban areas is 80 km/h, the average speed of highway transportation is 100 km/h, and the average speed of train transportation is 60 km/h. The time cost in this paper is adjusted according to the actual situation.

③ The transport cost of the train is 05, the transport cost of the general road is 1, and the transport cost of the highway is 15.

Explanation: Because railway is a short distance transportation mode between urban and suburban areas, its volume is small and its weight is low.

Table 3. Taiyuan city and suburban counties have different transportation modes

Type mode of transport	Transportation mode	Area	Number	Weight
two kinds	General Highway + Expressway	Qinxu	1	$\lambda_1 = 04$ $\lambda_2 = 06$
three kinds	General Highway + Expressway + Railway	Loufan Yangqu Gujiao	3	$\lambda_1 = 03$ $\lambda_2 = 06$ $\lambda_3 = 01$

Table 4. Transportation mode time cost from Taiyuan City to suburban districts and counties

Area	Railway(<i>h</i>)	General Highway(<i>h</i>)	Expressway(<i>h</i>)
Qinxu	—	0.88	1.00
Yangqu	0.77	0.83	0.67
Gujiao	1.28	1.13	1.00
Loufan	2.00	2.15	1.84

Table 5. *d* values from urban to suburban counties of Taiyuan City

Distance	Loufan	Gujiao	Qinxu	Yangqu
<i>d_{ij}</i>	5.9461	3.2269	3.1006	2.2053

Table 6. The spatial interaction between Taiyuan City and subcounties

	Loufan	Gujiao	Qinxu	Yangqu
Ranking	4	3	1	2
<i>I_{ij}</i>	0.1924	0.6532	3.5941	2.3692

Put the relevant data into the denominator of formula (1), that is, $d_{ij} = \sum_{i=1}^n \lambda_{ij} C_{ij} T_{ij}$, and calculate the *d* value between Taiyuan urban area and suburban area and counties, see Table 5.

Finally, the *K* value obtained in the first part and the *d_{ij}* value obtained in the second part are substituted into Eq. (6) to obtain the spatial interaction force between Taiyuan urban area and subdistricts and counties, as shown in Table 6.

5 Conclusions and Recommendations

5.1 Conclusions

- (1) There are significant differences in the spatial interaction force between Taiyuan urban area and suburban counties.
- (2) The distance between urban areas and suburbs is not a decisive factor for the spatial interaction between suburbs.

5.2 Recommendations

- (1) Steadily promote the construction of “one nuclear core, one circle and three clusters” in Taiyuan to promote the intraction between urban and suburban areas.

The construction of “one core, one circle and three groups” will make each new town become the anti-magnetic center of Taiyuan’s urban development, effectively promote the capital, technology, population and other production factors of the old city and the suburbs and counties around the new city to flow to the new city, promote the development of the county economy in the new city, and then drive the social and economic development of the suburbs and counties around the new city. At the same time, the construction of the new city can effectively evacuate the population and industries of the old city, relieve the traffic pressure of the old city, reduce the ecological load of the city, cure the “urban disease” of the old city, so as to enable the healthy development of the old city.

(2) Promote suburban interaction with the spatial transfer of urban industrial sectors.

At present, the development space of the city is small, the population is highly dense, and the land price is high, which is not conducive to the survival and development of the secondary industry with high energy consumption, high pollution and large land area. With the comprehensive promotion of the construction of modern new Taiyuan, some suburban counties (Qingxu County, etc.) have improved all kinds of supporting infrastructure conditions, enlarged the scope of developable regional space, and relatively low land price, which are superior places for the layout of the secondary industry. If the urban secondary industry such as metallurgy, chemical industry and other departments “stay put”, these departments and commercial catering industry, post and telecommunications industry, material supply and marketing industry, storage industry, financial industry, insurance industry, real estate, information and other industries for space and capital and other elements of the competition, which inhibits the development of urban secondary industry and inhibit the development of the tertiary industry; If suburban areas and counties do not combine their comparative advantages, open the door to absorb the urban secondary industry, take the closed route, it will be difficult to make the industry of suburban areas and counties have a new improvement.

(3) Optimize suburban population distribution and promote suburban interaction.

At present, the central urban area of Taiyuan is highly densely populated with great environmental pressure, while the population density of suburban counties is relatively low, the pressure of resources and environment is small, and the population development potential is huge. In view of the current situation of population distribution, it is suggested to actively develop livable small towns in suburban areas and counties, absorb part of rural surplus labor force locally, and reduce the amount of surplus labor force in suburban areas and counties to the main urban area.

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