Study on the Influence of Urban Spatial Connection of Beijing Tianjin Hebei Urban Agglomeration on Total factor Productivity

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Abstract. The development of a city can not be separated from the connection with the outside world. A city can benefit from the external effect of the connection network with other cities. This paper studies the relationship between cities' connection strength and TFP according to the network centrality index, which measures the level of the connection between cities. It is found that the connection between cities has a significant positive role in promoting the TFP of cities in a city cluster. The differences of labor scale, industrial structure and openness are the main factors that affect the connection between cities.

1 Introduction

In the urban network system, whether individual cities can benefit from the urbanization economy under the influence of network has not formed a consensus in academia. Some scholars believe that the gradually strengthened intercity connection can enlarge the economic effect of urbanization, that is, it can break through the limitation of individual city's own factors and have a positive effect on the city [1]. As for the network effect of urban agglomerations, some scholars have a concept, that is, the externality of urban networks, and they stress that this effect will affect the whole urban agglomerations[2]. Suwala (2013) believes that the intercity connection will create convenience for the actors at all levels in the urban agglomeration, such as enterprises, social organizations, individuals[3]. In the existing research, a large number of research results show that the participation of individual cities in the network is significantly related to their economic benefits[4]. There are even views that the contribution of external connections to the effect of urban development has exceeded its individual internal conditions[5]. Some domestic scholars have studied the relationship between regional spatial connection and regional economic growth, for example, Zhao (2015) finds that interregional linkages and spatial spillovers have a significant impact on regional economy[6]; Li (2014) studies the spatial connection of economic growth based on the provincial data over 30 years since the reform and opening up, and the results show that the network structure of economic spatial growth is stable[7], Miao(2018) studies the influence of the strength of regional overall connection on regional economic efficiency with ten major urban agglomerations in China[8].

To sum up, literature did little research concerning urban agglomeration and linkages' impact on specific city's economic efficiency. This paper tries to do some work in this field. With the yearly data of 2007, 2013 and 2017, the authors study the impact of urban spatial linkages on Total Factor Productivity (TFP), a commonly used measure of economic efficiency, in Beijing, Tianjin and Hebei.

2 Research method

2.1 Social network analysis

The central analysis in social network analysis can analyze the characteristics of each city's connection network. This paper uses this kind of index to measure the current situation of each city's external connection. Centrality is used to describe the central position of cities in the network. Cities in the center of the network are more convenient to access resources and information, and have greater power and influence 9. In this paper, the three most common centrality indicators are selected for analysis.

1. Degree centrality: according to the direction of economic connections, this indicator can be divided into outgoing degree and incoming degree, which respectively represent the degree of impact sent out and the degree of impact received. The calculation formula is shown in formula (1):

$$C_{(out)i}=\frac{d_{\ (out)\ i}}{k-1},\quad C_{(in)i}=\frac{d_{\ (in)\ i}}{k-1} \qquad (1)$$

In the formula, $C_{(out)i}$ is outgoing degree of i, $C_{(in)i}$ is incoming degree of i, $d_{\ (out)\ i}$ is the number of outgoing connections of i, $d_{\ (in)\ i}$ is the number of incoming connections of i, $k-1$ represents the number of theoretical connections between a point and the outside when the number of subjects is k.

2. Closeness centrality: it measures the proximity of the connection distance between nodes. The closer they are, the less controlled they are by other nodes. The

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specific calculation formula is shown in formula (2):

$$C_{c(i)} = \left[\sum_{i=1}^{n} d_{ij(c)}\right]^{-1} \quad (2)$$

In the formula, $d_{ij(c)}$ represents the distance between i and j, and the economic distance is used in this paper. The greater the proximity to the center, the higher the proximity to other cities.

3. Betweenness centrality: a measure of the "media" function of a node's connections. The only way to connect cities is often the throat, which can control the connection of other cities. The formula is shown in formula (3):

$$C_{(b)i} = \sum_{j<k}^{n} \frac{g_{jk(i)}}{g_{jk}} \quad (3)$$

2.2 Stochastic Frontier Analysis

In this paper, TFP represents economic efficiency with stochastic frontier analysis (SFA) as the calculating method. SFA, which decomposes the error term, is more suitable for the research of cross period panel data and the conclusion is more in line with the real situation10.

Based on the three factors input hypothesis, this paper selects three input indicators, namely, material capital input, land input and labor input. To prevent results deviation, this paper has two indicators, the regional GDP and the urban fiscal revenue, represent output.

On input indicators. First, material capital investment. At present, the official statistical department has no special statistical data, and most of the studies in China and abroad adopt the perpetual inventory method. The principle is to treat the relative efficiency as a geometric decline, and set the replacement rate as a constant, then the capital stock of this year = the capital stock of the previous year × (1-depreciation rate) + the investment of this year. Based on the research methods and preliminary estimation results of Dan (2008) 11, Sun et al. (2017) 12, this paper uses the national income of each city in 2007 to get the capital stock of that city in 2006, and then calculates the capital stock of the city over the years according to the capital stock in 2006 and the total fixed asset investment in that year. Second, land investment, this paper selects the land factors closely related to urban economic activities, and obtains the total built-up area of the city included in the urban agglomeration. Third, labor capital is measured by the number of employees in the statistical yearbook of each city.

3 Empirical analysis

3.1 Index calculation

3.1.1 Intercity connection

The economic connection matrix calculated based on the modified gravity model is imported into ucinet6.212, and the network centrality index data of urban nodes are processed, as shown in Table 1. Limited to space, the specific calculation results of the economic contact matrix are not listed.

Table1. Degree centrality

Ranking	Degree centrality			
	Outgoing degree		Incoming degree	
1	Beijing	94.444	Shijiazhuang	55.556
2	Tianjin	72.222	Beijing	44.444
3	Shijiazhuang	61.111	Baoding	44.444
4	Cangzhou	44.444	Cangzhou	44.444
5	Tangshan	38.889	Hengshui	44.444
6	Jinan	38.889	Xingtai	44.444
7	Baoding	33.333	Handan	44.444
8	Handan	33.333	Tianjin	38.889
9	Zhengzhou	33.333	Jinan	38.889
10	Langfang	27.778	Langfang	33.333
11	Hengshui	27.778	Tangshan	27.778
12	Xingtai	22.222	Anyang	22.222
13	Taiyuan	22.222	Taiyuan	22.222
14	Anyang	11.111	Chengde	16.667
15	Zhangjiakou	5.556	Qinhuangdao	16.667
16	Qinhuangdao	5.556	Zhangjiakou	11.111
17	Chengde	0	Zhengzhou	11.111
18	Shenyang	0	Shenyang	5.556
19	Huhhot	0	Huhhot	5.556

Table2. Closeness centrality

Ranking	Closeness centrality			
	Outgoing degree		Incoming degree	
1	Beijing	97.222	Shijiazhuang	68.519
2	Tianjin	86.111	Beijing	62.963
3	Shijiazhuang	80.556	Baoding	62.963
4	Cangzhou	72.222	Cangzhou	62.963
5	Jinan	69.444	Hengshui	62.963
6	Tangshan	68.519	Xingtai	62.963
7	Baoding	66.667	Handan	62.963
8	Langfang	62.963	Tianjin	60.185
9	Handan	61.111	Jinan	60.185
10	Zhengzhou	61.111	Langfang	57.407

Ranking	Closeness centrality			
	Outgoing degree		Incoming degree	
11	Hengshui	58.333	Taiyuan	50.926
12	Xingtai	55.556	Tangshan	50.463
13	Taiyuan	55.556	Anyang	48.611
14	Zhangjiakou	51.852	Chengde	46.759
15	Qinhuangdao	42.13	Zhengzhou	45.37
16	Anyang	41.667	Qinhuangdao	43.981
17	Chengde	0	Zhangjiakou	40.278
18	Shenyang	0	Shenyang	40.278
19	Huhhot	0	Huhhot	40.278

Table3. Betweenness centrality

Ranking	Betweenness centrality	
1	Beijing	27.394
2	Shijiazhuang	16.236
3	Tianjin	8.907
4	Tangshan	6.064
5	Handan	6.011
6	Jinan	4.781
7	Cangzhou	3.087
8	Baoding	3.038
9	Xingtai	2.768
10	Hengshui	1.534
11	Zhengzhou	0.558
12	Langfang	0.448
13	Taiyuan	0.218
14	Chengde	0
15	Zhangjiakou	0
16	Qinhuangdao	0
17	Anyang	0
18	Shenyang	0
19	Huhhot	0

3.1.2 Total Factor Productivity

According to the C-D production function, the stochastic frontier model is constructed, and the basic model is as follows:

$$InY_{it} = \beta_0 + \beta_1 LnK_{it} + \beta_2 LnL_{it} + \beta_3 LnN_{it} + \beta_4 t + (v_{it} - \mu_{it})$$
$$\mu_{it} = \mu_i \exp[-\eta(t - T)] \quad (4)$$

In the formula, Y_{it}, K_{it}, L_{it}, N_{it} represent urban output, capital input, labor input, land input respectively; v_{it} is random interference term and obeys normal distribution $N(0, \sigma_v^2)$, μ_{it} is a term of technical inefficiency and obeys the non-negative tail breaking normal distribution $N^+(\mu, \sigma_{it}^2)$, η is the rate of change of the term of technical inefficiency.

Using FRONTIER4.1 software, the estimated values of each parameter and technical efficiency (TE) of the model are obtained. The estimated results of the model are shown in Table 4.

Table4. Estimation Results of SFA Panel Data Model

Item	Coefficient	Standard error	T statistic
Constant term	-0.1508	1.2191	-1.2371
LnK	0.3330***	0.0891	3.7368
LnL	0.1208*	0.0675	1.7889
LnN	0.9655***	0.2034	4.7447
t	0.2911***	0.1070	2.7194
Sigma-squared	0.1929***	0.0527	3.6604
gamma	0.8981***	0.0414	21.6907
mu	0.8326***	0.1722	4.8340
eta	0.1650	0.5827	0.2832
Log-likeihood	3.0902		
LR test	43.0315		

Note: *** represents significance level < 0.01, ** represents significance level < 0.05, * represents significance level < 0.1.

It can be seen from the table that the fitting degree of the model is good. Among them, gamma = 0.8981 indicates that the model has an obvious composite error structure, indicating that the stochastic frontier model is more suitable for production function estimation than the traditional econometric model.

According to the definition of TFP, TFP of each region can be calculated by formula 5. The results are shown in Table 5.

$$TFP_{it} = \exp(\beta_0 + \beta_4 t) \times TE \quad (5)$$

Table5. Total factor productivity and its decomposition

City	2007	2013	2017
Beijing	1.0638	1.4250	1.9064
Tianjin	0.6753	0.9113	1.2191
Shijiazhuang	0.6199	0.8381	1.1213
Chengde	0.2469	0.3388	0.4532
Zhangjiakou	0.2827	0.3869	0.5177
Qinhuangdao	0.5069	0.4731	0.6158
Tangshan	0.6202	0.8171	0.9972
Langfang	0.6044	0.7350	0.9194
Baoding	0.5474	0.7413	0.9918
Cangzhou	0.5685	0.7454	1.1208
Hengshui	0.3295	0.4085	0.6355
Xingtai	0.5427	0.6734	0.9834
Handan	0.5505	0.8378	1.0292
Anyang	0.2987	0.4750	0.6329
Shenyang	0.3468	0.4603	0.6019
Huhhot	0.3372	0.4499	0.5465
Taiyaun	0.3687	0.5025	0.6722
Zhengzhou	0.3482	0.6872	0.9009
Jinan	0.4965	0.7693	1.0931

3.2 Model building

In order to test the impact of intercity linkages on TFP, the following empirical analysis model is established, as shown in formula (6):

$$TFP = \theta_0 + \alpha X + \sum_{j=0} \theta_{j+1} X_j + \mu_i + \varepsilon \quad (6)$$

In the formula, X is the core explanatory variable, i.e. intercity connection; X_j is the control variable. As the factors affecting the economic efficiency of urban agglomeration are not limited to explanatory variables, we need to separate these factors and highlight the role of explanatory variables. The population scale, openness, public service, industrial structure and infrastructure of the city are selected as the control factors.

3.3 Empirical results

3.3.1 Descriptive analysis

Table6. Descriptive statistics of variables

Variable	mean value	standard deviation	minimum value	maximum value
TFP	0.6840	0.3137	0.2469	1.9064
Degree centrality	2.0840	1.3706	0.0000	4.2405
Closeness centrality	2.7239	1.5670	0.0000	4.3832
Betweenness centrality	0.8239	1.2888	0.0000	4.0184
population scale	6.4260	0.4756	5.3974	7.2160
openness	20.4375	42.0052	0.1110	243.2900
public service	0.1411	0.0491	0.0686	0.3038
industrial structure	0.4469	0.1244	0.2577	0.8023
infrastructure	13.5043	4.3074	6.7700	22.7900

3.3.2 Regression results

Based on the panel data of 2007,2013 and2017, the empirical results in Table 7 are obtained, and the equation is significant as a whole. The degree centrality of the central explanatory variable is highly significant, which indicates that the central position of the urban agglomeration network promotes the TFP of the city; meanwhile, the population size, openness and industrial structure of the control variables all play a role in promoting. As the core explanatory variable, the closeness centrality and betweenness centrality are not significant in this study.

Table7. Estimation of the impact of intercity linkages on TFP

Variable	Coefficient	Standard error	T statistic
Constant term	-0.846***	0.308	-2.751
Degree centrality	0.137***	0.039	3.484
Closeness centrality	-0.016	0.031	-0.493
Betweenness centrality	0.030	0.019	1.568
population scale	0.159***	0.043	3.718
openness	0.001**	0.001	2.224
public service	-0.438	0.391	-1.12
industrial structure	0.689***	0.15	4.597
infrastructure	-0.002	0.004	-0.525
R^2	0.897	AdjustedR^2	0.880
F-statistic	52.335	Prob(F-statistic)	0.000

Note: *** represents significance level < 0.01, ** represents significance level < 0.05, * represents significance level < 0.1.

To sum up, the status of cities in the urban agglomeration network does have an impact on their TFP, that is, the connection between cities has a positive impact on urban development. How should cities improve their ability and status of connect with the outside world? This needs further study. Therefore, this paper further explores the impact mechanism of urban agglomeration network.

3.4 Model building

3.4.1 Analysis of influencing factors

Some factors, such as geographical location, traffic conditions and development level, will have an impact on the connection network. Most of the existing studies have studied the impact of traffic, investment and consumption, industrial structure, economic globalization on the formation of the connection network of the urban agglomeration13. The direct impact of traffic accessibility and geographical proximity on the connection network is obvious, and has been studied and confirmed by many scholars. Therefore, this paper focuses on the impact of the differences in labor, investment, industrial structure and economic openness on the network structure.

Table8. Variable matrix description

Variable	Symbol	Explain
Labor scale differences	$L(i,j)$	Based on the data of urban labor quantity, the matrix of labor difference between cities is constructed.
Labor wage difference	$S(i,j)$	Select the base city and calculate the difference of wage ratio between the two cities to construct the wage level difference matrix.
Investment difference	$I(i,j)$	Based on the data of urban fixed asset investment, the difference of the fixed asset investment proportion in each city is calculated to construct the investment difference matrix.
Industrial structure difference	$Ind(i,j)$ $Inds(i,j)$ $Indt(i,j)$	The difference matrix of industrial structure is constructed by calculating the ratio of the secondary and tertiary industries to the regional GDP between the two cities. In order to study accurately, the difference matrix of the second industry and the third industry will be constructed

		respectively.
Openness difference	$O\ (i,j)$	Calculate the ratio of the actual amount of foreign capital used by individual cities to the total amount of foreign capital used by all cities in the urban agglomeration. Take the median value of the ratio as the reference point, higher and lower than which are set as high and low level open cities respectively. Set value of high level one as 1, otherwise 0, and establish the matrix accordingly.

3.4.2 Model building

In this paper, QAP method is used to do multiple regression analysis for each variable. The model is constructed as follows:

$$R(i,j) = F\{L(i,j), S(i,j), I(i,j), Ind(i,j), O\ (i,j)\ \} \tag{6}$$

3.4.3 QAP empirical results

The results show that R2 is equal to 0.427 in the empirical test of Beijing Tianjin Hebei Urban Agglomeration, and the model interpretation effect is good. The correlation coefficients of the labor scale difference and the mutual openness relationship in Beijing Tianjin Hebei Urban Agglomeration are significantly positive. All of the above are important factors affecting economic ties.

Table9. Multiple regression analysis results of QAP

Explanatory variable	Standardization coefficient	
	Once regression	Second regression
L	1.268***	1.252***
S	-0.954***	-0.902***
I	0.362***	0.384***
Ind	-0.464***	-0.459***
$Inds$	-0.132	
$Indt$	0.160	
O	0.172**	0.170**
R^2	0.443	0.439
Adj-R^2	0.424	0.427
Number of samples	182	182
P value	0.001	0.001
Number of random permutations	2000	2000

Note: ***、**、* means significant at 10%, 5% and 1% confidence levels respectively.

4 Conclusions and recommendations

The main conclusions are as follows: (1) The connection between cities has a positive effect on TFP in urban agglomeration. (2) Besides geographical space and transportation factors, through the QAP analysis, it is found that the differences in labor market scale, industrial structure and economic openness also contribute greatly to economic ties.

Policy suggestions: (1) Enhance the openness of the city, actively connect with the outside world to seek development opportunities, and inject power into invigorating the economy. (2) Promote the establishment of an integrated labor market. (3) Promote industrial development in low-lying areas to achieve industrial upgrading, and guide the industrial structure and the advantages of technical personnel to reach the surrounding areas.

Acknowledgements

This article is supported by the fund project: Beijing Municipal Education Commission scientific research and postgraduate training co-construction project "Research on urban traffic development strategy in Beijing in the context of new urbanization".

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