Comparing China's city transportation and economic networks

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Abstract: The city system has been a prevailing research issue in the fields of urban geography and regional economics. Not only do the relationships between cities in the city system exist in the form of rankings, but also in a more general network form. Previous work has examined the spatial structure of the city system in terms of its separate industrial networks, such as in transportation and economic activity, but little has been done to compare different networks. To rectify this situation, this study analyzes and reveals the spatial structural features of China’s city system by comparing its transportation and economic urban networks, thus providing new avenues for research on China’s city network. The results indicate that these two networks relate with each other by sharing structural equivalence with a basic diamond structure and a layered intercity structure decreasing outwards from the national centers. A decoupling effect also exists between them as the transportation network contributes to a balanced regional development, while the economic network promotes agglomeration economies. The law of economic development and the government both play important roles in the articulation between these two networks, and the gap between them can be shortened by related policy reforms and the improvement of the transportation network.

Key Words: City system; transportation network; economic network; network centrality; intercity relationships.

1 Introduction

The city system, a crucial element in economic and social development, is a spatial distribution structure in a region, country or the world consisting of cities of different types and sizes. There are cooperative and complementary relationships between cities, suggesting that all cities exist in a heavily connected network and every city in the city system is a network node, whose formation is driven by the spatial concentration and diffusion of economic activities.

Arising as an advancement on the traditional view of the world as a 'mosaic map' of political boundaries, Taylor’s (2003) city network research has gradually aroused the interest of academics. Conceiving the world city network as the 'skeleton' upon which contemporary globalization has been built, and city network research encompasses the infrastructure network (primarily concerned with transportation networks) and the economic network (encompassing the economic linkages between cities). Different networks can reflect different aspects of the city system, thus a comparative study between different networks can provide insight into a deeper understanding of the formation and evolution of the city system.

The interaction between transportation and city systems has been a constant theme of urban and transportation geography, while the economic linkages between cities depict city systems from another important aspect. Since transportation and economic networks have both provided the means for extracting resources over long distances and of integrating all cities into a single system, and there should be certain linkages between them. The key research question in this paper, therefore, concerns how the city transportation network 'articulates' with the structure of the city economic network. This is of particular interest for several reasons: transportation systems can have a multiplier effect through the industrial chain to stimulate additional employment and investment opportunities in different industries; the transportation network can fundamentally alter the economic linkages between cities through the movement of goods and people; and rapid economic development of a city can trigger a greater employment-related movement of people to and from the city.

China is chosen as an example to inspect and analyze these two networks. This is valuable *per se*. As a country occupying a vast territory, a large population and with significant regional disparities, China's rapid economic growth and urbanization development in recent years has increasingly attracted attention from across the world, making it an archetypal location for city network research.

The paper proceeds as follows: in section 2 we systematically review the related literature, in section 3 we analyze China's transportation network and economic network, in section 4 we compare the similarities and differences of these two kinds of city networks. Concluding remarks are provided in section 5.

2 Literature Review

As the connections between cities is becoming increasingly complicated instead of comprising purely vertical and horizontal linkages, and the social network analysis method is widely used, city system research has progressed from the analysis of city attributes, to the inspection of intercity relationships in networked societies, that is, city network research (Camagni, 1993). City network research mainly comprises research into the infrastructure network and the economic (or corporate organization) network, especially in the global context (i.e., the world city network). Infrastructure network research is primarily concerned with transportation and telecommunication networks, with airline linkages (Smith & Timberlake, 2002; Matsumoto, 2004; Derudder & Witlox, 2005, 2008; Neal, 2010) offering the best illustration of the transportation role in the city system, and the Internet (Townsend, 2001a, b; Malecki, 2002; Vinciguerra, Frenken and Valente, 2010) representing the mainstream telecommunication network. City network studies regard air passenger flows as the optimal measurement of the city transportation network (Knox & Taylor, 1995). In China's case, although the matured rail network can provide insights into the evolution of China's city system (Dai, Jin and Wang, 2005; Zhong & Lu, 2011), China's air transportation network has developed enormously in the past decade and now connects most big cities. Therefore, it can largely represent the spatial structure of China's city system (Yu, Gu and Li, 2008), with an increasing number of studies based on air passenger flows having been conducted in recent years (Jin, Wang and Liu, 2004; Wang & Jin, 2007; Ma & Timberlake, 2008; Shaw et al., 2009; Wang et al., 2011; Lin J, 2012; Xiao et al., 2013) to align China's research more with international practice.

The other aspect of city network research is the economic network that is usually measured in corporate organizations, focusing on the ownership links between firms across space. In contrast with the infrastructure network, the research on the economic network is relatively subjective, which uses proxies and modeling method because it is impossible to obtain the actual volume of economic linkages, such as the Interlocking Network method proposed by Taylor (2003). Taylor, Evans and Pain (2008) use the interlocking network model to measure relations between 200 cities within and beyond polycentric urban regions based on the office networks of advanced producer service firms; Using data on the headquarter and branch locations of the world's 500 largest multinationals, Alderson, Beckfield and Sprague-Jones (2010) employ techniques developed for the analysis of networks to evaluate more than 6300 cities to analyze the intercity relations in the world city system; Van Oort, Burger and Raspe (2010) employ data on inter-firm relations in the Dutch Randstad to test the spatial and functional integration and urban complementarities in economic network relations.

Each type of the city network, like the aforementioned infrastructure network and the economic network, captures a substantively important dimension of intercity relationships, thus reflecting the different structures of the city system. The comparison between different city networks can provide insights into understanding intercity networks formed by different spatial flows. Nevertheless, only a little research focuses on this topic. This includes Choi, Barnett and Chon's (2006) comparative study of world city networks in terms of Internet backbone and air transportation intercity linkages, as well as Mahutga et al.'s (2010) research on the comparison between the global city hierarchy gauged by international air traffic flows and the structure of the world system based on international commodity trade. Though a large body of studies has focused on the important relationship between the transportation and the economic development of regions, without discussing it from the city network perspective. Among these, many studies have provided evidence of a strong link (causal relationship in both directions) between transportation infrastructure and economic development (Banister & Berechman, 2000; Bose & Haque, 2005; Fedderke, Perkins and Luiz, 2006; Zhou et al., 2007; Fernandes & Pacheco, 2010; Banerjee, Duflo and Qian, 2012; Pradhan & Bagchi, 2013; Beyzatlar, Karacal and Yetkiner, 2014). Generally speaking, the transportation infrastructure is established in advance to promote economic growth, while economic development in turn influences further improvements in transportation, while other studies also analyze the governments' important role in the articulation between the transportation and economic development (Bowen, 2000; Ishutkina & Hansman, 2008).

In conclusion, therefore, a significant deficiency in the city network research is the lack of comparability, with multiple layers of city networks having been examined independently of each other. As Mahutga et al. (2010) put forward, the city network literature is full of discussions of the articulation between the world city system (referring to the ranking of city centrality in the air transportation network) and the world system (that is, the power and position of a country in the world system measure by international trade flows), but there is surprisingly little empirical research. To rectify this situation of lacking comparative studies, taking China as an example, whose city network is large and complicated enough to be analyzed, we develop networks based on both intercity traffic flows and economic linkages, calculate city centrality in the network and explore the network topology of intercity relationships, subsequently compare the two perspectives to examine their structural similarities, differences and interrelationships. While city network studies usually focus on the world city system and western countries, it is interesting to look at China's situation of surging economic growth and the prosperous development of air transportation in the past few years. Does China also conform to some findings obtained from city network studies in Western countries and all over the world?

Though there is a great deal of literature on the relationship between transportation infrastructure and economic development, it generally analyzes the interaction or causal relationships involved using statistical approaches. This study, however, will examine the relationship between transportation and economic development from the perspective of a comparative analysis by the city network method. It is of great significance to compare the city transportation network with the economic network. First, the intercity transportation system usually comes in the form of network, and intercity economic linkages can also be regarded as networks, so it is reasonable to use the city network method for their analysis. Second, these two networks are both depictions of city systems from different aspects, and there exists an intimate connection between them, which makes a comparative study feasible. Third, from the perspective of comparative analysis, the detailed similarities and differences between transportation and economic networks, as well as regional disparities in these two networks can be revealed. This leads to the further exploration of the underlying reasons and related policy implications, which a purely correlation and causal analysis cannot discern. Finally, this study provides empirical evidence of the articulation between different city networks for future research, thus contributing to deepen research into the city system and urban geography by introducing a new research method to analyze the relationship between transportation and economic development, and broadening the research scope of city network studies from the perspective of comparative studies.

3 Data and Analysis

3.1 Analysis of China's City Transportation Network

Transportation routes, and cities located along routes, combine to constitute an open network system, with cities as the network nodes and transportation routes as the links between the cities. Airlines, railways and highways are all related to city development to some extent, thus affecting the formation of the city system by supporting and guiding city spatial development with their own network properties. Among them, China's air transportation network is an important and advanced system of intercity transportation, and highly correlated with the urban hierarchy (Figure 1(a)).[1] As mentioned earlier, unlike other forms of transportation infrastructure in China, access to relevant aviation data is quite easy. Accordingly, we analyze 118 prefecture-level cities with airports in terms of air passenger flows. The air transportation network - composed of nodes (airports) and links (airlines) - reflects the exchange flows and connectivity between cities. More air passengers imply closer connections between cities. We collect data of air transportation from *China Transportation Statistical Yearbook (2013).*

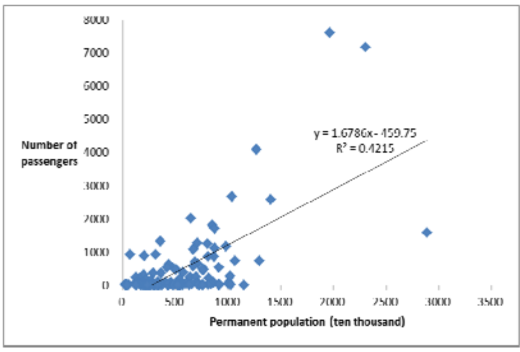


Figure 1(a) Number of air passengers and permanent population of China's prefecture-level cities in 2010

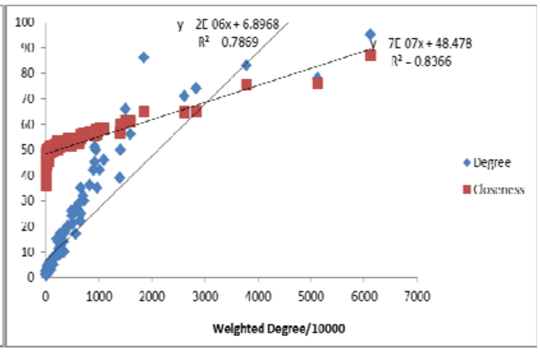


Figure 1(b) The relationship between weighted degree, degree and closeness of cities in 2012

3.1.1 Analysis of City Centrality in the Transportation Network

In order to identify the structural characteristics of the city system as manifested by air passenger flows, it is necessary to understand the urban hierarchical structure based on city centrality rankings in the air transportation network. Here we simply use the weighted degree centrality metric in network analysis, i.e. the number of links upon a node, with the number of air passengers as the weight, to measure the city centrality (Mahutga et al., 2010):

$$C_i = \sum_{j=1}^{n} a_{ij} x_j \qquad (1)$$

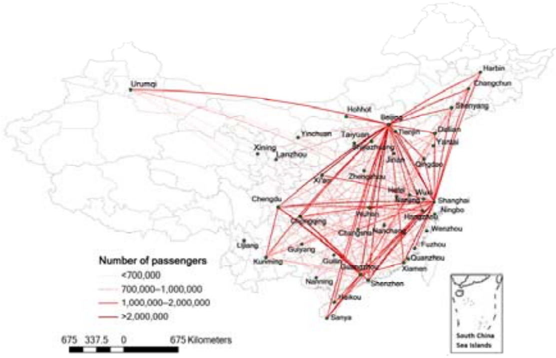
where we define C_i as the weighted degree centrality, which reflects the connection intensity of city *i* with other cities in the air transportation network, indicating the relative importance of city *i* in the national air transportation network; a_{ij} denotes the number of air passengers between city *i* and city *j*; x_j denotes the degree centrality of city *j*.

As it is known to all, there are several centrality measurements in the network analysis, such as degree centrality, closeness centrality, betweenness centrality, et al. The reason why we employ the weighted degree is that it takes in consideration the volume of passengers between cities while other centrality measures in a binary value representation cannot, and weighted degree is also in direct proportion to degree and closeness significantly (Figure 1(b)). And we exclude the betweenness measurement because the betweenness values of many cities are 0.

Table A1 in the Appendix presents China's top 42 cities ranked by 2012 city centrality of the air transportation network as defined by the weigthed degree centrality. From this, we can regard the top 6 cities as national aviation centers with the absolutely leading centrality (Beijing, Shanghai, Guangzhou, Shenzhen, Chengdu and Kunming), the following 12 cities in Table A1 as regional aviation centers and prime aviation nodes (Chongqing, Xiamen, etc.), and the remaining 24 cities as provincial aviation centers and aviation nodes (capitals of provinces, some tourism cities and open coastal cities). Moreover, as national and regional aviation centers, those 18 cities nearly spread all over China's major regions.

3.1.2 Analysis of Intercity Relationships in the Transportation Network

Due to the difficulty in obtaining data for intercity relationships and the space limitation of analyzing spatial interactions between all cities, we apply a convenient alternative in their analysis by selecting 42 main cities in Table A1 as representatives. These typical cities feature in China's city system (see Figure A1 in the Appendix), thus enabling us to elucidate the basic pattern of intercity relationships illustrated in Figure 2(a).[2]



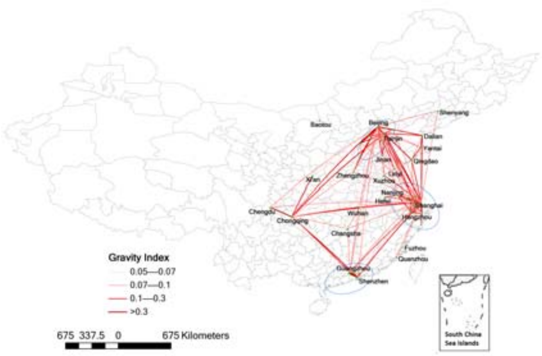


Figure 2(a) Air passenger flows between the 42 cities (2012)

Figure 2(b) Gravity indexes between the economic 42 cities in network in 2012(b=1)

Intercity relationships are operationalized as numbers of air passengers between cities to depict the basic structure of China's city transportation network. It is evident from Figure 2(a) that the air transportation network contains the following three essential features:

(1) As national aviation centers, Beijing, Shanghai, Guangzhou, Shenzhen, Chengdu and Kunming have the most flights from and to other cities, so the closest relationships in the air transportation network are also present between these 6 cities. These are followed closely by their relationships with other cities, thus forming a basic diamond structure with 4 key nodes (Beijing, Shanghai, Guangzhou—Shenzhen, Chongqing lying between Chengdu and Kunming) in the network. The edges and diagonal lines of the 4 vertices are among the most significant air routes in China. The sphere of influence of each city (number of air passengers>1,000,000, only 50 linkages included) is illustrated in plain sight in Figure 2(a): as the capital of China, Beijing has the biggest effect covering the North, East and West China Regions, followed by Shanghai, with its influence encompassing the eastern coastal areas, and Guangzhou-Shenzhen with an influence range involving the South and Southwest China Regions. In addition, 2 national aviation centers in western China – Chengdu and Kunming effectively link western China with eastern China.

(2) The relationships of 12 regional aviation centers with national centers occupy the first place in their outward linkages, followed by their relationships with non-adjacent regional aviation centers, for instance, Chongqing and Xiamen (894137 passengers), Hangzhou and Urumqi (855967 passengers), Xi'an and Xiamen (794187 passengers).

(3) Eastern cities, with more intensive air passenger flows, account for a higher proportion of the 42 cities than do cities in other regions. In general, intercity relationships are closer in the east.

3.2 Analysis of China's City Economic Network

A few investigations have been conducted into the economic network of the city system (Van Oort, Burger and Raspe, 2010), with the network nodes representing different individual agents as diverse as firms, banks, even cities and countries, and the links between the nodes representing their mutual interactions, e.g., ownership, R&D alliances, or trade relationships (Schweitzer et al., 2009). Much work has focused on the economic linkages between cities, viewing growth pole theory (Perroux, 1950), spatial interaction models (Ullman, 1954), core-periphery theory (Friedmann, 1966) and spatial diffusion theory (Hagerstrand, 1968) as the *initial development phase*; the network research on city systems as the *rapid development phase* (Goetz, 1992; Mun, 1997; Schönharting et al., 2003); and multinational firm networks, industrial location and industrial agglomeration as the *comprehensive development phase* (Camagni & Salone, 1993; Gordon & McCann, 2000; Alderson, Beckfield and Sprague-Jones, 2010; Derudder et al., 2010). To simplify the research problem, we define the city economic network as a network consisting of intercity relationships attributable to spatial economic activities, namely, economic linkages between cities. Drawing on China's previous urban studies and taking into account the availability of data, we apply the urban flow method to analyze city centrality and a spatial interaction model to analyze intercity relationships in the economic network. Related economic data are gathered from *China City Statistical Yearbook (2013)*.

3.2.1 Analysis of City Centrality in the Economic Network

City centrality in the economic network can be measured by urban flow intensity. Originally proposed in the Urban Development Research Project of the Longhai-Lanxin Region conducted by the China Academy of Urban Planning & Design in 1994, urban flow refers to the intercity interactions – the flow of passengers, cargos, information, funds and technology between cities. So urban flow intensity is defined as the impact of a city's external function (agglomeration and diffusion effects) on its relationships with other cities, and is extensively used for evaluating a city's hierarchical position in regional economic linkages (Zhu & Yu, 2002; Zhang et al., 2004; Chen & Song, 2011). A city's economic activities can be divided into basic and non-basic parts: the basic part, also known as external functions, serves for the non-local demands, constituting the city's economic foundation; while the non-basic part, namely internal functions, serves for the local demands (Alexander, 1954). Therefore, the external functions of a city signify the economic activities of its intercity relationships, that is, its economic interaction with other cities. Since urban flow intensity represents a city' s economic relationship strength with other cities or a city' s external functions, it can clearly reflect a city's roles as key nodes in the economic network, i.e. network centrality. Urban flow intensity has been used extensively in research relating to China's intercity relationships and city hierarchical structure since its origin.

Urban flow intensity is given by

$$F_i=N_i \cdot E_i \qquad (2)$$

where F_i is the urban flow intensity of city *i*, N_i signifies the efficiency of city *i*'s external function, i.e. the actual impact of city *i*'s per unit external function, and E_i denotes city *i*'s external function. Here, we establish the urban hierarchy by ranking cities in terms of city centrality measured in urban flow intensity.

We choose the employment figure as the indicator of city function, and whether city *i* has external function E_i depends on its location quotient in the employment of each sector.[3] The location quotient of employment for sector *j* in city *i* is represented by

$$Lq_{ij}=\frac{G_{ij}/G_i}{G_j/G} \quad (i=1, 2 \ldots m;\ j=1, 2 \ldots n) \qquad (3)$$

where G_{ij} refers to the employment of sector *j* in city *i*; G_i refers to the employment of all sectors in city *i*; G_j denotes the employment of sector *j* in the region (province) to which city i belongs; and *G* denotes regional employment. If the location quotient of sector *j*, $Lq_{ij}<1$, the proportion of employment of sector *j* in city *i* is smaller than that of sector *j* throughout the region, which indicates it does not have an external function, i.e. $E_{ij}=0$. When $Lq_{ij}>1$, it indicates that sector *j* in city *i* can provide external services to other cities, so its external function E_{ij} can be expressed as

$$E_{ij}=G_{ij}- G_i \cdot (G_j/G) \qquad (4)$$

The total external function E_i of *n* sectors of city *i* can be calculated as

$$E_i=\sum_{j=1}^{n} E_{ij} \qquad (5)$$

where N_i, the function efficiency of city *i* represents the per capita GDP, i.e.,

$$N_i=GDP_i/G_i \qquad (6)$$

with G_i denoting the employment of city *i*.

Given the operability and representativeness of indicator selection, we use the employment data of 15 industries - engaged in providing external services - to compute urban flows: as presented by Table A2 and A3 in the Appendix, the top 42 cities measured by 15 industries are exactly the same with those measured by 13 industries except for some small changes in order; compared with the result measured by 11 industries, the top 42 cities measured by 13 and 15 industries are closer to the fact of city economic development in China, with the average GDP of the latter(64898143 ten thousand RMB) much larger than the former (50519789 ten thousand RMB).

Table A2 summarizes the urban flow intensity and GDP of the main cities in 2012, indicating that Beijing, Suzhou, Shanghai, Tianjin, Shenzhen and Guangzhou boast the highest urban flow intensity making them national economic centers, and that the following 12 cities (Shaoxing, Hangzhou, etc) are regarded as regional economic centers, with the remaining cities being provincial centers. Then we analyze intercity economic relationships based on the main 42 cities in Table A2 (which cover all of China's major regions) with urban flow intensity and GDPs much higher than other cities. Each major region in China is represented by at least one city among them, such as Xi'an representing the Northwest China Region.

3.2.2 Analysis of Intercity Relationships in the Economic Network

In addition to investigating inter-firm relationships between cities to discuss the city economic network, it is noteworthy that the Gravitational Model, a valuable branch of spatial interaction models in geography, is extensively applied in city network research. Spatial interaction models have been used to predict the size and direction of spatial flows between cities that result from a human process, encompassing measurements of the origin and destination cities and distance dependence function. These models have a broad scope of application including transportation flows (Matsumoto, 2004; Neal, 2010), migration flows (Chun, 2008; Chun & Griffith, 2011), commodity flows (LeSage & Llano, 2006; Murat Celik & Guldmann, 2007) and telecommunication flows (Guldmann, 1999; Krings et al., 2009; Gao et al., 2013). Similarly, spatial interaction models can also be used to measure the economic linkages between cities. Since its inception by Taaffe (1962), the intercity economic link, which is directly proportional to city population size and inversely proportional to distance, has also been widely used to research China's intercity economic links (Miao & Wang, 2006; Gu & Pang, 2008; Meng & Lu, 2009).

Therefore, we analyze intercity economic relationships based on the gravity model with the top 42 cities in Table A2. According to the gravity model, the intercity relationship (I_{ij}) between city i and city j, termed the gravity index, is directly proportional to city size（M_i, M_j）and inversely proportional to D_{ij}, the distance between cities, so that

$$I_{ij} = K \frac{M_i M_j}{D_{ij}^b} \qquad (7)$$

where K and b are constants that can be obtained through regression methods.

The gravity index reveals the intensity of intercity relationships. Since intercity relationships are affected by their population, economic factors of cities and the geographic distance between cities, the size of city i is measured by the equally weighted summation of GDP and permanent population after data normalization (Li & Yang, 2009). For the convenience of calculation, the friction coefficient b and other constants (K and f) are all assumed to be 1. Regarding the value of b, compared with b=2, gravity indexes of b=1 are less influenced by the distance between cities

(See Figure 2(b) and Figure A2 in the Appendix). Hence, in contrast with the usual friction coefficient *b* of 2, we avoid the excessive influence of distance on intercity relationships by using 1 as the value of b, which is also empirically verified by Wang, Wu and Wang (2006). The effect of distance on intercity economic links has also been considered in Figure A3 in the Appendix.

The average gravity index is 0.05 by calculating the gravity indices of the 42 cities from Equation (7). Figure 2(b) illustrates that intercity economic relationships[4] higher than this average value exist chiefly between Beijing, Suzhou, Shanghai, Tianjin, Shenzhen, Guangzhou and other cities, which implies that the strongest economic relationships are between these 6 national economic centers and their adjacent cities: Guangzhou and Foshan (Gravity index=2.55), Shanghai and Suzhou (Gravity index=1.80), Beijing and Tianjin (Gravity index=1.45), Suzhou and Wuxi (Gravity index=0.90), Guangzhou and Shenzhen (Gravity index=0.86). As Figure 2(b) shows, the most significant intercity relationships exist in the 3 dominant metropolitan areas and Chengdu-Chongqing Region, especially in Beijing-Tianjin-Hebei Metropolitan Area and Yangtze River Delta Metropolitan Area with much denser linkages. Similar with the air transportation network, we simply regard the influence scope of each city reaching other cities as including the linkages with the gravity index no less than 0.1(74 linkages included). Figure 2(b) indicates the influence range of national centers mainly concentrate in the 3 dominant metropolitan areas, only reaching cities in adjacent regions(such as Beijing influencing Qingdao) as far as Chengdu-Chongqing Region. A clear picture of a diamond structure has come into being in the city economic network with Beijing-Tianjin, Shanghai-Suzhou, Guangzhou-Shenzhen and Chongqing (lying between Chengdu and Xi'an) occupying the four vertices and with Wuhan as the midpoint. In addition, intercity relationships between adjacent cities are also relatively close. Last but not least, the intercity relationships in the middle, west and northeast are a lot weaker than in the east.

4 A Comparative Analysis between the Transportation Network and the Economic Network

4.1 Basic Analysis

The transportation and economic networks are two important aspects of network research concerning city systems. After studying these aspects in isolation, we conduct a comparative analysis to determine the articulation between these two networks, by dividing the research question in the Introduction section into the following related sub-questions: To begin with, is there a direct correlation in the city centrality between the transportation and economic networks? Second, is there any structural equivalence in the structure of intercity relationships between these two networks? Finally, is the clustering pattern in the network similar to each other?

Hierarchy of cities: comparing centrality indices

The city centrality is an individual-level measurement identifying each city's relative position in a hierarchy. To solve the first question proposed above, we apply correlation analysis to compare the hierarchy of cities in these 2 networks. The correlation tests are summarized in Table 1. Table 1 presents the top 25 cities ranked by the centrality of the air transportation network and ranked by the centrality of the economic network. Pearson's r (city centrality correlation coefficient) and Spearman' rho (city rank correlation coefficient) can only be measured by the prefecture-level cities that have airports (because not all cities have airports in China). Therefore, the results of the correlation analysis will be biased to some extent on account of the data limitation. The centrality scores are normalized indicating 1 as the maximum. Beijing, Shanghai, Guangzhou and Shenzhen are members of the top 6 cities, i.e., the national centers, in both networks. The association between the two networks by city centrality and related rankings is significant: Pearson's correlation coefficient is 0.756 ($p < 0.01$) and Spearman's rho is 0.514 ($p < 0.01$).

Table 1 Correlations of centrality indices and rankings between the air transportation and economic networks

Rank	Transportation network		Economic network	
	City	Centrality	City	Centrality
1	Beijing	1.000	Beijing	1.000
2	Shanghai	0.837	Suzhou	0.945
3	Guangzhou	0.617	Shanghai	0.783
4	Shenzhen	0.462	Tianjin	0.731
5	Chengdu	0.426	Shenzhen	0.481
6	Kunming	0.301	Guangzhou	0.447
7	Chongqing	0.260	Shaoxing	0.372
8	Xiamen	0.244	Hangzhou	0.364
9	Xi'an	0.229	Wuxi	0.349
10	Hangzhou	0.227	Qingdao	0.326
11	Sanya	0.178	Dalian	0.318
12	Haikou	0.165	Dongguan	0.316
13	Nanjing	0.159	Jinan	0.297
14	Urumqi	0.153	Tangshan	0.285
15	Shenyang	0.151	Chongqing	0.281
16	Harbin	0.151	Chengdu	0.276
17	Dalian	0.147	Wuhan	0.265
18	Qingdao	0.135	Xuzhou	0.260
19	Guiyang	0.118	Jinhua	0.254
20	Fuzhou	0.113	Quanzhou	0.245
21	Changsha	0.109	Changsha	0.241
22	Nanning	0.106	Foshan	0.236
23	Wuhan	0.104	Baotou	0.231
24	Tianjin	0.104	Nanjing	0.226
25	Changchun	0.092	Hefei	0.209
Correlation	Peason's r	0.756	Spearman's rho	0.514
Sig.		0.01		0.01

Structural equivalence: QAP analysis

To address the question of whether or not a pair of networks is structurally similar at a system level, we perform the quadratic assignment procedure (QAP) function in UCINET VI to correlate each pair of matrices. The correlation analysis result of transportation network and economic network with the top 42 cities shows that there is significant correlation between them (correlation coefficient is 0.340, $p<0.001$), implying a similar pattern of intercity relationships.

Hierarchical cluster analysis

Despite the fact that each network is composed of multiple clusters and multiple subgroups within each cluster, the hierarchical cluster analysis demonstrates no isolated group of cities detached from other cities in each network. The dendrograms of our hierarchical cluster analysis of the air transportation and economic networks are respectively presented in Figure A4(a) and (b). A shorter bracket means a stronger relationship between a pair of cities.

We can find out that in the air transportation network, 2 national centers—Beijing and Shanghai forms the strongest bond and starts the first subgroup, and this subgroup grows with the addition of the fourth city in the centrality ranking—Shenzhen, and then joined by Chengdu and Guangzhou, which lends support to the basic dimaond strucutre with strongest connections between the 4 vertices. Beginning with the strongest bonds, only other loosely connected cities are added to enlarge the original cluster. Inspite of many subgroups in the dendrogram, they haven't formed any major clusters separately due to the overlapping wide influence scopes of aviation centers.

In terms of the economic network dendrogram, it is evident that the geographical proximity matters most in intercity relationships: the strongest bonds exist between national centers and their adjcent cities—Beijing and Tianjin, Shanghai and Hangzhou, Guangzhou, Foshan and Shenzhen. This network can be broken into 3 major clusters around the core cities of 3 dominant metroplitan areas, suggesting that the influence areas of these 6 national centers are respectively confined to the metropolitan area that they belong to, also including some peripheral cities: such as Zhengzhou and Qingdao near the edge of Beijing-Tianjin-Hebei Metropolitan Area, Chengdu and Chongqing on the outskirts of Pearl River Delta Metropolitan Area.

The comparison of dendrograms beween these two networks indicates the clustering pattern in the network is different from each other, thus resolving the last question.

4.2 Analysis of Similarities

In terms of city centrality, China's main cities can be divided into national, regional and provincial centers in both the transportation and economic networks. Membership of the core group (national centers) is relatively stable and the top tier in both networks consists of Beijing, Shanghai, Guangzhou and Shenzhen. The correlation coefficients (Pearson r and Spearman's rho) between the two networks in terms of city centrality indices and rankings are significant, suggesting a structural similarity between the air transportation and the economic networks.

In terms of intercity relationships, the QAP result indicates a certain degree of structural equivalence in these two network, which can also be demonstrated by the similarities of spatial patterns of intercity relationship in these two networks: there is a notable spatial polarization trend and obvious layer structure in the two networks—intercity relationships decrease outward from the 6 national centers to periphery areas; overall, a basic diamond structure with Beijing, Shanghai, Guangzhou-Shenzhen and Chongqing occupying its four vertices is evident in both the transportation and economic networks.

4.3 Analysis of Differences

From the perspective of city centrality, among the top 42 cities ranked by city centrality in transportation and economic networks, only 24 cities are identical. We find that the ratio of the top 42 cities in the transportation network is 19:6:13:4, in the east, middle, west and northeast regions of China respectively, while the corresponding ratio in the economic network is 32:4:4:2. This implies that the transportation network focuses more on the equitable distribution of traffic hubs and the convenience of intercity transportation links, and the western region contributes a relatively large share of aviation centers owing to its vast area. In contrast, hub cities of the economic network are mainly influenced by regional economic development, making them concentrate in the eastern coastal area, so the middle, west and northeast regions have much fewer cities as economic centers, with only 10 cities ranking among the top 42 cities. Similarly, all 6 national centers are eastern cities in the economic network while 2 out of 6 cities are western cities in the air transportation network. Western cities have played a more important role in the development of the transportation network than the economic network.

From the perspective of intercity relationships, the national transportation centers exhibit the widest scope of influence: Beijing is a gateway to connections with the North, East and West China Regions; Shanghai to the eastern coastal area; Guangzhou and Shenzhen to the South and Southwest China Regions; Chengdu and Kunming links the western region with the eastern coastal area. In terms of economic networks, the 6 national centers have intimate relationships with adjacent cities, but their economic influence is less than those in the transportation network, being restricted to within the 3 corresponding Metropolitan Areas. The result of the hierarchical cluster analysis also provides further evidence for the fact that the 6 national centers have wider influence ranges in the transportation network than the economic network. Moreover, intercity relationships in the economic network are more influenced by geographical proximity than the transportation network —a shorter distance leads to a closer relationship between cities.

5 Conclusions

This paper studies China’s spatial structure of city systems in terms of its transportation (air passenger flows) and economic networks, revealing China’s city systems from two different perspectives, which provides an innovative approach to research into China’s city network. The findings of this study illustrate that the ranking of current city centrality and patterns of linkages between cities have established an urban hierarchy that makes particular cities become nodes with national and regional control capabilities: air passenger flows and economic linkages are concentrated in a few core cities in China, with most other areas remaining peripheral, reflecting the inequitable development of the city system. Furthermore, by comparing the transportation and economic networks with each other, we can conclude that the transportation network relatively contributes to a balanced regional development by attaching more importance to the convenience of communication between cities, while the economic network enhances the agglomeration economies, laying more stress on the improvement of city efficiency and the promotion of economic growth. It is worth noting that a balanced regional development facilitated by the air transportation network can only occur by taking into account the economic network too.

Different from existing researches, this study analyzes the interconnection between air transportation and economic development in China through city network comparative analysis, which provides a fresh perspective for city network research in China from a spatial standpoint. The result shows that the structure of air transportation network relates to the economic network in urban China to some extent, which is similar to the aforementioned studies in Literature Review: the widespread air transportation network supports the national economic development, and the spatial pattern of economic activities captures the crucial aspect of location advantage that moulds an air transport network. However, there exists certain uncoupling effect between these two networks, i.e., the actual economic development level in western cities lag behind their corresponding transportation development, due to the important role of government in choosing the locations of airports from different cities by focusing more on spatial equity(regional balanced development) than spatial efficiency(agglomeration economies). Though the siting of air transportation hubs are mainly decided by the government (Civil Aviation Administration of China), the air passenger flows between cities are still influenced by geographic demands for air transportation, which are constrained by regional development disparities (Graham, 1998). Therefore, the air transportation network has a significant relationship with intercity economic linkages. The foundation of the national economic integration is supported by a developed transportation infrastructure network, whose location, quality and accessibility will greatly affect the economic distance between 2 cities. Therefore, the air transportation network will play an important role in accelerating the economic development of cities in the middle and western regions of China, gradually shortening the gap between the transportation and economic networks. Currently, China's agglomeration economy degree is on the rise, while the agglomeration of production factors (especially labor force) lags behind the economic development, resulting in the expansion of regional disparity. In order to realize relative spatial equity and a rational city system, the full mobility of production factors between regions need to be enhanced by related policy reforms (such as relaxing the household registration policy) and the improvement of transportation infrastructure.

Notes

1. Only permanent population can represent each city's real size and only national population censuses (the most recent one is conducted in 2010) have the corresponding statistics. Due to the limitation of data availability, we use data of 2010 instead of 2012 to depict the relationship between number of air passengers and permanent population of China's prefecture-level cities.
2. Due to the consideration of clarity, we only choose the top 170 linkages larger than 400,000 to be shown in the map.
3. There are a few assumptions of the location quotient: the whole country has no export for foreign trade; the national industrial structure is a standard structure which meets the needs of national population; each city has the same level of productivity and consumption structure. For research purpose, we can neglect the foreign trade part. However, since there are huge differences between cities in China, using the national industrial structure as the standard structure to reveal the differences of economic development level between cities can be very biased. To reduce this bias, the industrial structure of each province instead of the whole country is employed as the standard to analyze the external function of each city. To solve the problem of some cities independent from any province, according to the actual fact of economic zones, we combine Beijing, Tianjin and Hebei Province into Beijing-Tianjin-Hebei Region, Shanghai, Jiangsu Province and Zhejiang Province into Yangtze River Delta Region, Chongqing and Sichuan Province into Chengdu-Chongqing Region, also delete Lhasa and Xining in Xizang and Qinghai Province.
4. Due to the consideration of clarity, we only choose the top 181 linkages larger than 0.05 to be shown in the map. On account of the limited space in the map, the 3 dominant metropolitan areas are represented by the 3 ellipses in the map: from north to south, they are respectively Beijing-Tianjin-Hebei Metropolitan Area

(including 7 cities) with Beijing and Tianjin as its centers, Yangtze River Delta Metropolitan Area (including 12 cities) with Shanghai, and Suzhou as its centers, and Pearl River Delta Metropolitan Area (including 6 cities) with Guangzhou and Shenzhen as its centers.

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Appendix

Table A1. Ranking of main cities by weighted degree centrality in the transportation network (2012)

City	Centrality	City	Centrality	City	Centrality
Beijing	61290024	Shenyang	9285898	Jinan	4857302
Shanghai	51305356	Harbin	9282767	Guilin	4212985
Guangzhou	37810080	Dalian	9054625	Yinchuan	3825325
Shenzhen	28362486	Qingdao	8317162	Lanzhou	3706185
Chengdu	26168868	Guiyang	7267975	Nanchang	3414845
Kunming	18516102	Fuzhou	7002171	Hefei	3354278
Chongqing	15983796	Changsha	6728881	Ningbo	3328521
Xiamen	15021240	Nanning	6554542	Hohhot	3318084
Xi'an	14088270	Wuhan	6434405	Xining	2714711
Hangzhou	13955887	Tianjin	6411218	Wuxi	2634608
Sanya	10983735	Changchun	5685501	Lijiang	2632713
Haikou	10172733	Zhengzhou	5650636	Yantai	2396889
Nanjing	9766196	Wenzhou	5052178	Shijiazhuang	2327524
Urumqi	9431839	Taiyuan	4960923	Quanzhou	2123685

Table A2. Urban flow intensity and GDP of main cities measured by 15 industries (2012)

City	GDP(10000 RMB)	Urban flow intensity	City	GDP(10000 RMB)	Urban flow intensity
Beijing	178794000	34077444.3	Foshan	66130223	8127829.9
Suzhou	120116500	32216516.2	Baotou	34095400	7959964.8
Shanghai	201817200	26714717.5	Nanjing	72015700	7784412.9
Tianjin	128938800	24936412.9	Hefei	41643400	7222070.9
Shenzhen	129500601	16447945.8	Jiaxing	28905730	6819389.1
Guangzhou	135512072	15298137.7	Yantai	52813800	6607894.9
Shaoxing	36540321	12750596.6	Baoding	27209000	6587201.3
Hangzhou	78020058	12492972.7	Fuzhou	42182887	6519643.0
Wuxi	75681500	11969449.3	Ningbo	65822064	6493026.2
Qingdao	73021100	11196656.1	Nantong	45586700	6488887.7
Dalian	70028306	10920530.3	Maoming	19361785	6365998.6
Dongguan	50101727	10843416.8	Handan	30242864	6316001.2
Jinan	48036762	10201616.6	Huizhou	23675499	6157070.1
Tangshan	58616363	9811132.5	Cangzhou	28124212	5929983.5
Chongqing	114096000	9669020.2	Shenyang	66025865	5638592.6
Chengdu	81389438	9483930.1	Zhengzhou	55497869	5563580.0
Wuhan	80038200	9112714.1	Xi'an	43661000	5516848.1
Xuzhou	40165800	8948939.8	Linyi	30128100	5098432.4
Jinhua	27107675	8742316.0	Changzhou	39698700	5084095.9
Quanzhou	47264953	8441484.0	Shijiazhuang	45002098	4841599.6
Changsha	63999097	8312753.7	Taizhou	29112616	4661316.4

Notes: 15 industries are listed below: Manufacturing; Production and Distribution of Electricity, Gas and Water; Construction; Transport, Storage and Post; Information Transmission, Computer Service and Software; Wholesale and Retail Trades; Hotels and Catering Services; Financial Intermediation; Real Estate; Leasing and Business Services; Scientific Research, Technical Services and Geological Prospecting; Management of Water Conservancy, Environment and Public Facilities; Education; Health, Social Securities and Social Welfare; Culture, Sports and Entertainment. To test the robustness of the urban flow method, we use the most common method-GDP of each city to measure its economic strength and compare the ranking of main cities with that by urban flows, and the result shows that 33 cities out of the top 42 cities are the same with Table A2.

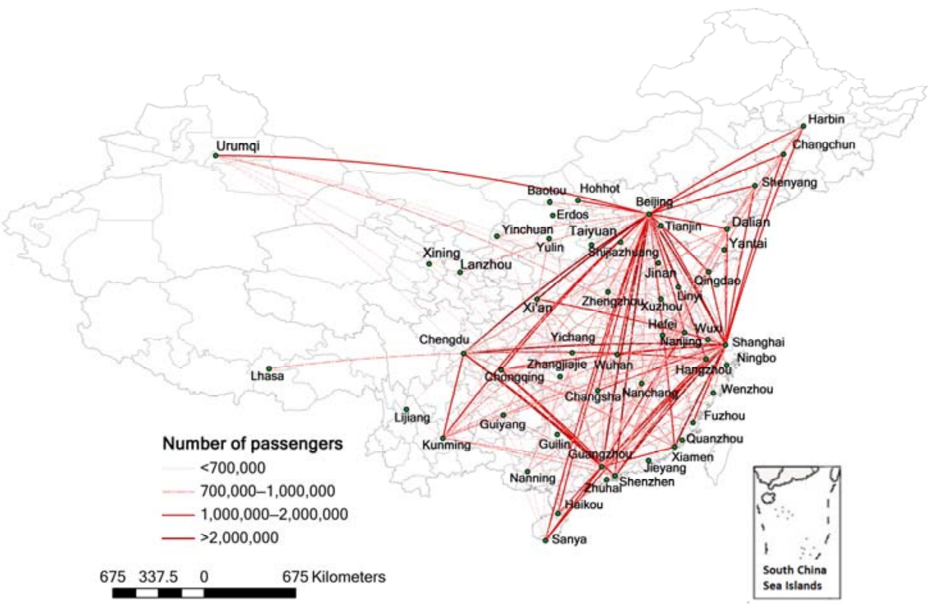
Table A3. Ranking of main cities by urban flow intensity measured by different industries (2012)

Rank	**15 industries**	**13 industries**	**11 industries**
1	Beijing	Beijing	Beijing
2	Suzhou	Suzhou	Shanghai
3	Shanghai	Shanghai	Guangzhou
4	Tianjin	Tianjin	Shenzhen
5	Shenzhen	Guangzhou	Nanjing
6	Guangzhou	Shenzhen	Changsha
7	Shaoxing	Shaoxing	Shenyang
8	Hangzhou	Hangzhou	Jinan
9	Wuxi	Wuxi	Hangzhou
10	Qingdao	Qingdao	Dalian
11	Dalian	Dongguan	Xuzhou
12	Dongguan	Jinan	Harbin
13	Jinan	Dalian	Dongguan
14	Tangshan	Chongqing	Wuhan
15	Chongqing	Tangshan	Xi'an
16	Chengdu	Chengdu	Changchun
17	Wuhan	Wuhan	Chengdu
18	Xuzhou	Jinhua	Daqing
19	Jinhua	Quanzhou	Yichang
20	Quanzhou	Foshan	Xuancheng
21	Changsha	Xuzhou	Shijiazhuang
22	Foshan	Nanjing	Hohhot
23	Baotou	Changsha	Kunming
24	Nanjing	Baotou	Handan
25	Hefei	Hefei	Suqian
26	Jiaxing	Jiaxing	Jieyang
27	Yantai	Yantai	Maoming
28	Baoding	Nantong	Lu'an
29	Fuzhou	Fuzhou	Nanning
30	Ningbo	Baoding	Qingdao
31	Nantong	Ningbo	Yancheng

32	Maoming	Maoming	Nanchang
33	Handan	Huizhou	Zhanjiang
34	Huizhou	Cangzhou	Cangzhou
35	Cangzhou	Handan	Nantong
36	Shenyang	Shenyang	Nanchong
37	Zhengzhou	Zhengzhou	Heze
38	Xi'an	Linyi	Dongying
39	Linyi	Changzhou	Zhoukou
40	Changzhou	Xi'an	Xiamen
41	Shijiazhuang	Taizhou	Liaocheng
42	Taizhou	Shijiazhuang	Zhengzhou

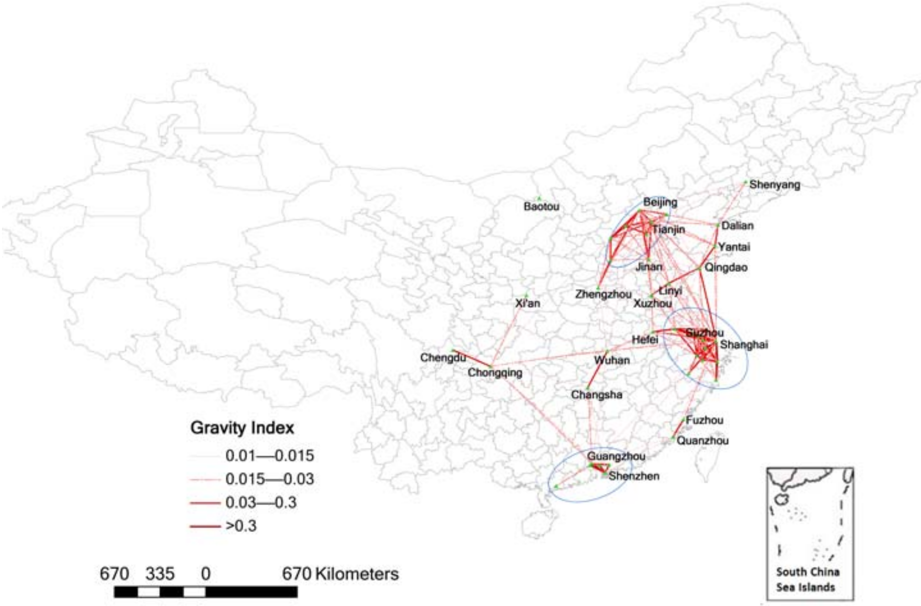
Notes: 13 industries exclude 2 industries from 15 industries—Production and Distribution of Electricity, Gas, as well as Water Management of Water Conservancy, Environment and Public Facilities; while 11 industries exclude 2 industries from 13 industries—Manufacturing and Construction.

Figure A1. Air passenger flows between the 52 cities (2012)



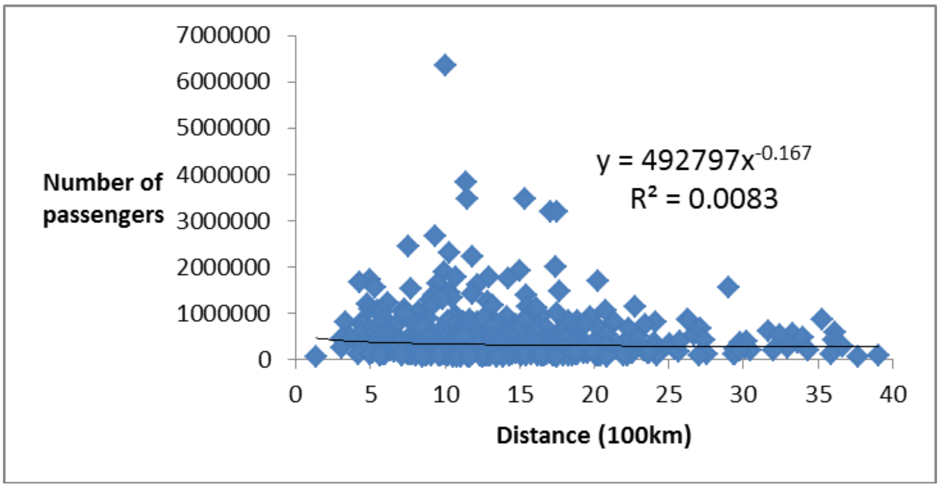
Notes: Due to the consideration of clarity, we only choose the top 178 linkages larger than 400,000 to be shown in the map. Compared with 42 cities in Figure 2(a), after adding 10 cities, the number of dominant linkages larger than 400,000 only increases by 8, indicating the difference between Figure 2(a) and A1 can be neglected.

Figure A2. Gravity indexes between 42 cities in the economic network in 2012(b=2)



Notes: Due to the consideration of clarity, we only choose the top 171 linkages larger than 0.01 to be shown in the map. The fact that b value being 1 is better than 2 can also be proved by the value of their coefficients of variance, among which the case of b=2 is larger (CV_2=12.189>CV_1=2.823), meaning the economic linkages measured by gravity indexes when b=2 are more concentrated between neighboring cities.

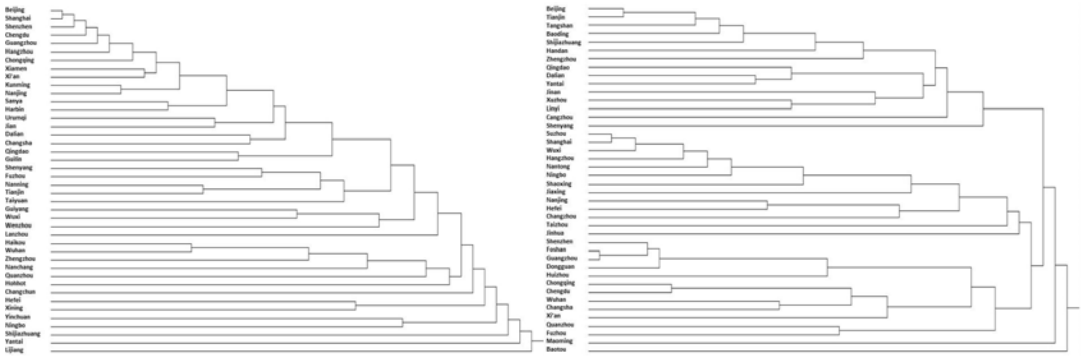
Figure A3. The inverse relationship between the number of air passengers and the distance between cities



Notes: The intercity relationships in the economic network (Figure 2(b)) are much more influenced by the geographic proximity than the transportation network (Figure 2(a)), possibly caused by the selection of gravity index as the measurement of intercity relationships in the economic network. The gravity index is in inverse relation with the distance between cities, however, intercity relationships in the transportation network are demonstrated directly by the air traffic flows between cities(the number of air passengers). By analyzing the relationship between the number of air passengers and the distance between cities, we discover that there exists a weak correlation between the intercity relationships in the transportation network and the distance as shown in

Figure A3, thus relatively reducing the influence of distance on the intercity relationships in the economic network and making the result of comparative analysis reasonable.

Figure A4. Dendrogram of the hierarchical cluster analysis of city networks



(a) Dendrogram of the hierarchical cluster analysis of the air transportation network

(b) Dendrogram of the hierarchical cluster analysis of the ecomomic network