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The configurations of Chinese national urban systems in both high-speed railway and airline networks

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Abstract

Although entering the transportation market at a later stage in 2003, Chinese HSR networks have become the largest in the world and are even growing faster than airline networks. Using 2013 origin/destination (O/D) passenger flow data, we compare the spatial configurations of Chinese urban systems in both high-speed railway and airline networks at the national scale. The outcome shows that, HSR dominant cities and links are mainly centralized in the middle and eastern parts of China offering regional connections, whereas air dominant cities and links are evenly distributed in the whole China offering interregional connections. That is mainly a result of that compared to airline networks, the strength of cities in HSR networks is more sensitive to socio-economic performance of cities, while the strength of links in HSR networks is more sensitive to the geographical distance between linked cities. Furthermore, HSR networks promote agglomeration economies of urban systems along the trunk lines in specific regions, whereas air networks relatively contribute to a more balanced urban development in China.

Keywords: High Speed Railways (HSR), airlines, passenger flows, China, urban systems

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1. Introduction

Urban systems are made up of city nodes and of various kind of (social, economic and political) interactions that materialize to some extent through transportation and information flows (Meijers 2005; Devriendt et al. 2010). Even though Information and Communication Technologies (ICTs) overwhelmingly facilitates instant communication, face to face interactions are still important in the contemporary world (Bertolini and Dijst, 2003). High-speed physical transportations such as airlines and high-speed railways (HSR) which can dramatically decrease geographic and temporal constraints of moving people for business transactions, tourism, post-migratory travels for keeping social links with friends and relatives, academic collaborations and political activities, are still crucial for facilitating the formation of functional urban systems (Hall and Pain, 2006).

Seen the important role of high-speed transportation networks on linking urban areas, the development of airlines and HSR has been supported with substantial capital and infrastructure investments in China to stimulate integration of the national urban network (Ng and Wang, 2012) and its future integration with Euro-Asian urban systems by the Belt and Road Initiatives (Chen and Zhang, 2015). Regarding airline transportation networks, China's ranking in scheduled seats was merely 37th in the world in 1978, but rose to 2nd after 2005. The number of airports (civil certificated schedule airport) in mainland China increased from 94 in 1990 to 216 in 2016, and is expected to reach 260 in 2020 according to the 13th five-year plan of China's contemporary and comprehensive transportation system (Fu et al., 2012; NDRC, 2016). Although entering the transportation market at a later stage in 2003, Chinese HSR networks (Figure 1) have become the largest in the world and are even growing faster than airline networks, even though HSR length per capita is less spectacular (Delaplace and Dobruszkes, 2016). Until to the end of 2015, Chinese HSR networks have reached a total of 19,000km accounting for over 60% of the global level, and can cover more than 70% of the population and 80% of the GDP (Wang et al., 2015; NDRC, 2016).

Figure 1 The HSR planning in China until 2020 (made by authors)

Up to now, a great deal of the existing literature have been focused on functional relationships of urban systems by using schedule seat airline flow data across the world (Smith & Timberlake 2001; Derudder & Witlox 2005; Derudder & Witlox 2009; Van Nuffel et al. 2010). However, HSR travel has received less attention and the few available studies on the functional relationships of urban systems in Europe (Hall and Pain, 2006) and China (Zhang et al., 2016) at the regional or sub-regional scales are based on time schedule HSR data. Like airline travel, HSR has been considered alone instead of jointly with other longdistance transportation modes. The only exception is the study of Xiao et al. (2013) who used passenger data of conventional railways and airlines to estimate a reversed gravity model to identify attractions of a limited number of cities in China. To the best of our knowledge, no study is available on the comparisons of urban systems in both two high-speed transportation networks at the same national scale and by using the same type of passenger flow data. Our research tries to fill these gaps. Thus, the key research question in this paper is how the use of both networks articulates the configuration of national urban systems using the actual HSR and air passenger flows. This is of particular interest for two reasons. First, as we will argue in the next section, the functional relationships of urban systems at a larger spatial scale would be better reflected by passenger flows travelling (i.e. the demand side) than by the provision of rail or air services (i.e. the supply side) (Yang et al., 2017). Second, both HSR and airline networks in China mainly carry people from the middle to upper-middle classes, that is, social groups that have stronger travel demands for functional activities such as high-end business, advanced producer services and tourism (Delaplace and Dobruszkes, 2016; Liu and Kesteloot, 2015). The relevant functional relationships of urban systems might differ in both high-speed transportation networks with their different network properties. Consequentially, the comparisons of the configurations of urban systems in both transportation networks could provide an insight into the future high-speed transportation and urban system planning.

This paper is structured as follows. Section 2 presents the literature review. Section 3 explains our analytical framework, after which we introduce both HSR and airline O/D flow data. In Section 4, the results of our analyses are discussed, which consist of a general overview of HSR and airline passenger flows at the national scale. This section is followed by a comparison between them. The final section comprises the conclusions of the paper and an outlook on some future research issues.

2. Literature review

For understanding the functional relationships between cities, studies on transport networks have taken a prominent role in the space of flows at different spatial scales. The traditional internal “space of places” has given way to the external “space of flows” proposed by Castells (1996), which emphasizes functional relationships between cities. In the theory of “space of flows”, there are three layers determining the flows of information, people, and capital. The first layer is the infrastructure layer of the material support for the flows. The second layer contains different nodes and hubs which are connected and organized by the infrastructure layer. The third layer is that people exercise the directional functions (Derudder & Taylor 2005).

As to the three layers, two types of popular empirical approaches emerged to assess the external flows among cities. The first approach is based on the derived flows of advanced tele-information contacts (Devriendt et al., 2010), advanced producer services (APS) (Zhao et al., 2015), and business elite contacts (Beaverstock, 2004) within the three layers. However, strong criticisms exist on the ‘derived flow approach’. The main argument is that it cannot reflect the extent to which the internal characteristics of nodes can be translated into the external interaction (Robinson, 2005), which means the derived linkages of people, information, and service from node attributes cannot reflect in which direction and to what extent flows are actually produced by people (Neal, 2010). Therefore, a better alternative approach is based on actual corporeal flows in the first transport infrastructure layer by means of either schedule data (the supply side) or actual passenger data (the demand side).. Airline scheduled seats have been used to investigate the structure of world cities at the global scale (e.g., Smith & Timberlake 2001; Choi et al. 2006; Derudder & Witlox 2005) and inter-regional airline transport linkages in Europe (Derudder and Witlox, 2009; Van Nuffel et al., 2010), the USA (Derudder et al., 2013) and China (Lao et al., 2016; Ma and Timberlake, 2008). In contrast, only a few scholars have considered HSR travel to investigate interactions between cities. For instance, Zhang et al. (2016) used the HSR time schedule data to approximate the actual passenger flows to uncover the relationships of cities in the Yangzi River Delta (YRD) region in China and Hall & Pain (2006) used the scheduled train flows to identify the polycentric urban regions in Europe.

However, both airline and HSR data raise several issues. First, it is common to consider supply-related data (typically the number of seats offered between two cities, or sometimes train frequencies or seatkm's). The rationale for supply-side data relies on the fact it says something about carriers' strategies that are expected to draw networks according to existing and potential interactions between places served. However, the supply is by definition larger or equal to the demand, so at best it can be considered as a proxy for actual flows of people (Neal, 2014). Second, supply or demand data are usually given at the individual legs of trips rather than the trip as a whole. For instance, if air or rail passengers travel from A to B where they connect to C, usual figures would count the number of (airline or HSR) seats or passengers between A and B and between B and C but not between A and C via B. As a result, transfers distort the picture of actual intercity relationships (Derudder et al., 2010; Derudder and Witlox, 2008, 2005). As far as air travel is concerned, some researchers have addressed this issue by using the so-called MIDT dataset, which is based on actual origins/destinations air travellers flew from/to (Derudder et al., 2007). However, information is based on bookings made through global distribution systems (GDS). It means that those travellers who directly book on airlines' websites are not included. This could arguably lead to biases, for instance, an underestimation of people flying by low-cost airlines[1].

Finally, HSR timetables are difficult to convert into the number of seats for two reasons. First, many HSR routes are served by heterogeneous rolling stock (e.g., shorter vs. longer trains or single- vs. double-deck trains). This means that if a train operator would pursue a high-frequency strategy (that is, the operation of frequent services but with likely less capacity per train), the alleged interactions between cities derived from HSR frequency would be biased. Second, provided the number of HSR seats is nevertheless available (e.g., from the train operator or thanks to homogeneous rolling stock), one still needs to consider that most high-speed trains (HSTs) call at several intermediate stations. This involves uncertainties on how seats are split between the various city-pairs thus served. For instance, if a Beijing (A) to Shanghai (D) HSR service calls at Jinan (B) and Nanjing (C), then seats are potentially sold for A-B, A-C, A-D, B-C, B-D and C-D city-pairs. Either the train operator pre-allocates seats to all pairs or the actual bookings make the split change in real time. But in both cases, this information is usually not available to researchers. It is thus not surprising that Yang et al. (2017) found that the scheduled train flows actually

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[1] *In Europe for instance, European low-cost airlines have long kept out of GDS to avoid extra costs.*

can to a large extent underestimate the positions of major cities in the urban system, especially in China with a larger-than-average capacity in the trains running from and to these major tier cities to satisfy the demands of passenger travel.

As a result of all these limitations, there is a strong rationale for investigating urban systems (1) through demand-related data, which (2) are based on true origins and destinations (Neal, 2014). Of course, such data are usually not fully available (or even not available at all) for scholars. Commercial privacy and confidentiality dominate academic purposes, even in the strictly controlled railway sector in China (Liu et al., 2015).

In sum, the literature review above indicates that currently the research on both airline and HSR network research is largely based on time schedule data instead of the actual number of passengers carried by transportation networks between cities, which can lead to some misunderstanding of the functional urban system. Furthermore, world city research using airline data and the regional urban system research using HSR data only include a limited number of cities at the global and regional scale, respectively. There is no comparison between the roles of high-speed railway and airlines on the configuration of urban systems with a large number of cities at the same spatial level. Our research tries to fill the gaps by the applications of both HSR and airline O/D passenger flows to compare the configurations of urban systems in the two high-speed transportation networks at the national scale in China.

3. Methodology

3.1 Data description

In this study, cities are the nodes in the networks. The relationship between nodes is operationalized as the number of actual number of HSR and airline passengers travelling between cities. In China, there are four types of cities: municipalities, sub-provincial and provincial capital cities, prefecture-level cities and county-level cities (Ma, 2005). Country-level cities are merged with the prefecture-level cities since most cities do not have airports and HSR stations and are under the administration of relevant prefecture-level cities. If there are cities with multiple HSR stations and airports, those terminals have been merged into one node. For example, if node *i* is Beijing and node *j* is Shanghai, a_{ij} represents the HSR or airline passenger flows between the two urban areas. The HSR passenger matrix was collected by the Transportation Bureau of the China Railway Corporation, including the total actual numbers of aggregated HSR O/D passengers travelling between pairs of cities[2]. The data cover the 105 existing HSR cities (Figure 2) (4 municipality-level, 21 sub-provincial/provincial capital level and 80 prefecture-level cities) and 1675 city links (passenger volume larger than 0) in China in 2013 (over 436 million passengers). The airline passenger matrix was collected by the Civil Aviation Administration of China and includes a total actual number of O/D air passengers travelling between pairs of cities. The data cover the 168 existing airport cities (Figure 2) (4 municipality-level, 32 sub-provincial/provincial capital level and 132 prefecture-level cities) and 1467 links (passenger volume larger than 0) in China in 2013 (over 306 million passengers). In the end, we obtained 51 cities with both HSR and airport terminals and 144 city pairs with both HSR and airline connections in 2013.[3]

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[2] *According to China classification of HSR services, these are D and G trains.*

[3] *Due to the fact that HSR passenger flow data are rarely accessible for researchers especially at the national scale in China, we could only compare both HSR and airline passenger flow data in 2013 instead of the up-to-date data in 2016.*

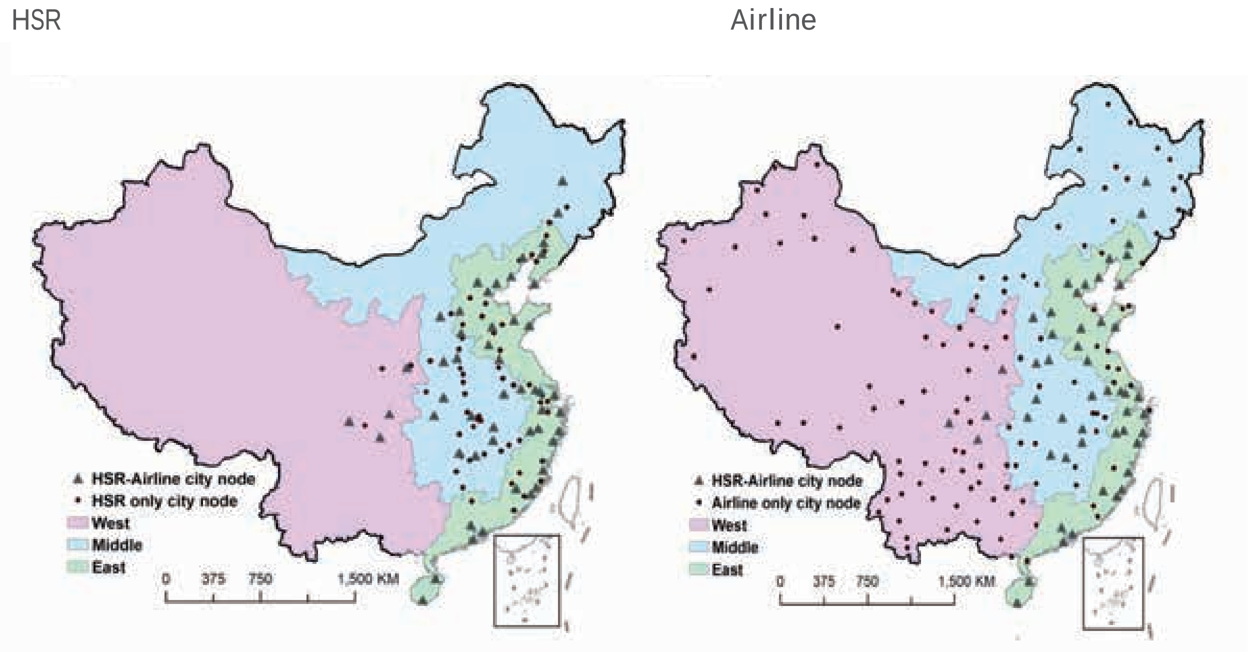

Figure 2. The distribution of HSR and airline cities[4]

It is worth noting that airline and HSR travel is arguably not representative of all medium- and longdistance travel within China. Indeed, there is clear evidence that the poor and even a part of the middle class have much less access to airlines and HSRs due to relative high monetary travel cost than conventional railways (Delaplace and Dobruszkes, 2015; Wang et al., 2013). For instance, migrants living in cities favour conventional (lower-speed) trains to visit other cities notably because it is much cheaper (Liu and Kesteloot, 2015). In addition, various cities are neither served by HSR services nor by air services. Therefore, our research does not capture the full set of functional interactions between cities. Instead, our research is focused on urban systems as reflected by both HSR and air passenger flows, which favour mobilities of the upper social-occupational groups (business activities, government officials, premium tourism or VFR (visiting friends and relatives) travel, etc).

3.2 Analytical framework

3.2.1 Measures of the city centrality and link connectivity

To identify the structural characteristics of the urban system as manifested by airline and HSR passenger flows, it is necessary to understand the urban hierarchical structure based on city centrality and connectivity rankings in the transportation network. We measure configuration of the urban systems by adapting the framework presented in Limtanakool et al. (2007) and Van Nuffel et al. (2010) in which two strength indices (namely, city strength and link strength) are used to measure the city centrality and link connectivity.

$$DIT_i = \frac{T_i}{(\sum_{j=1}^{J} T_j/J)} \tag{1}$$

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[4] The division between the west, middle and east is based on NBSC (2011).

Where we define DIT_i as the city centrality, indicating the relative strength of city i in the national transportation network. T_i is the total number of passenger volumes associated with city i, and i≠j. Cities with DIT_i values above 1 are considered dominant because they are more important than the average of the other cities in the network. To compare the different positions of cities in the two transportation networks, we further categorized 3 classes of dominant cities (the first class with a DIT value larger than 10 as national dominant cities, the second class with a DIT value between 5 and 10 as regional dominant cities, and the third class with a DIT value between 1 and 5 as local dominant cities (Wang and Jing, 2017).

$$RSL_{ij} = \frac{t_{ij}}{\sum_{i=1}^{I}\sum_{j=1}^{J} t_{ij}} \qquad (2)$$

Where we define RSL_{ij} as the connectivity of a city pair, indicating the relative strength of a link connected by the national transportation network. t_{ij} is the total number of passengers travelling between cities i and j, and i≠j. RSL_{ij} is the value for all links in the network sum to unity, while individual values range from 0 to 1. A value of 1 represents the highest strength of a link. Since some RSL values will be rather small, to clear understand their strength values, the RSL value is multiplied by 1000 (Derudder and Witlox, 2009). According to the multiplied value of link strength, we categorized 5 classes of dominant city links (the first class with a RSL value larger than 20, the second class with a RSL value between 10 and 20, and the third class with a between 5 and 10, the fourth class between 1 and 5.

We further perform a multiple linear regression to investigate the differential impacts of attributes of urban systems on the city and link strength in both transportation networks. Following the existing literature, in Table 1 we considered a mix of geographic, social, economic and political attributes related to cities as potential covariates.

Table 1. Independent variables for regression analysis

Variables	Information	Source	Mean_HSR	SD_HSR	Mean_Airline	SD_Airline
City strength						
GDP per (million yuan)	Gross domestic product per capita for a city	Chinese urban statistical yearbooks 2014	3712.4	3989.6	2549.6	3431.5
Population (inhabitants)	Population for a city		578.5	428.7	452.2	402.9
Average distance (km)	The average distance of one city to other cities connected by HSR or airline networks	Calculated by authors from GIS	551.4	175.2	914.2	320.8
Administrative level	Hierarchical administrative level (scored)	(Ma, 2005)	2.7	0.5	2.8	0.5
	3=Municipality level city 2= Sub-provincial/ regional capital level city 1 = Prefecture city					
Link strength						
Summed GDP per (million yuan)	Summed gross domestic product per capita for each city pair of origin and destination	Calculated by authors	9361.4	6604.1	12145.1	6923.8
Summed population (inhabitants)	Summed population for each city pair of origin and destination		1264.0	607.5	1489.3	854.0
Distance (km)	The geographical distance between a city pair		605.3	363.3	1086.2	583.1
Summed administrative level	Summed administrative level for each city pair of origin and destination		5.3	0.8	4.5	0.7

3.2.2 Hierarchical cluster analysis (HCA)

It should be noticed that each transportation network could be composed of multiple clusters and multiple subgroups as community networks. Community networks refer to city nodes that are gathered into several groups in which there is a higher density of city-pair connections within groups than among groups. HCA is a community detection algorithm based on modularity proposed by Newman and Girvan, (2004). The basic concept of the HCA algorithm is to evaluate the result of the network partitioning, which computes the difference between the number of links within communities and the expected number.

$$Q=\sum_{m=1}^{n}\left[\frac{l_m}{L}-\left(\frac{d_m}{2L}\right)^2\right] \qquad (3)$$

We define Q as the modularity value; the higher the value of Q, the better the community structure is. n denotes the total number of communities in the network, L is the total number of passengers in the transportation networks, l_m is the total number of passengers in the community m, d_m is the total number of cities in community m.

4. Results

4.1 The comparison of city strength between HSR and airline networks

4.1.1 City strength

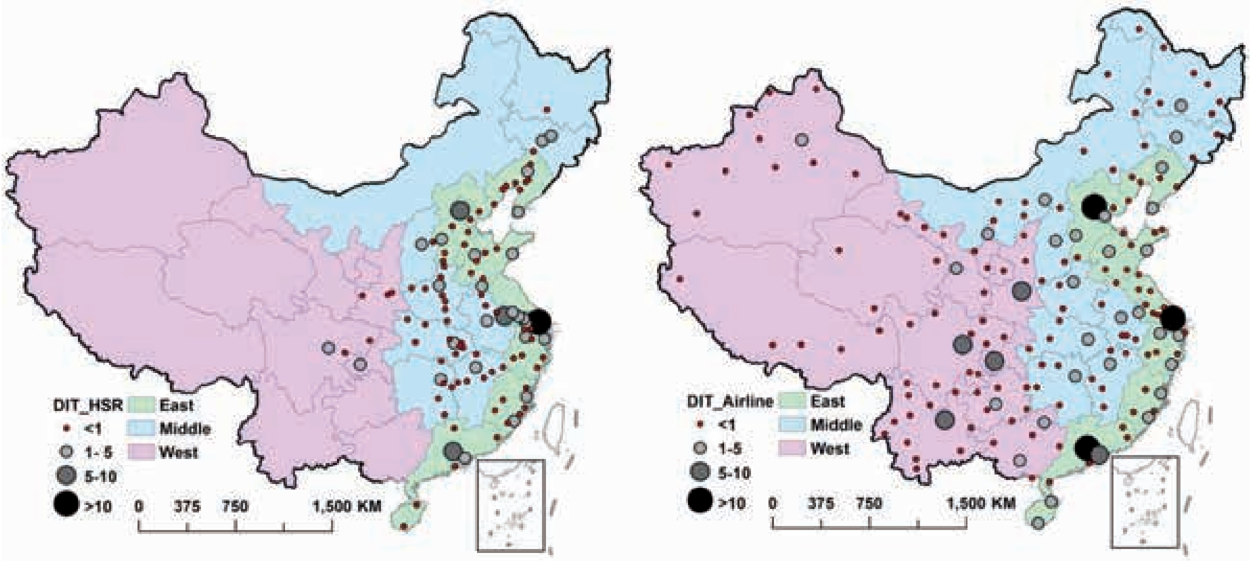

Figure 3 The city strength of HSR (left) and airline (right) networks.

As shown in Figure 3, 29 of 105 HSR cities and 37 of 168 airline cities are dominant (that is, DIT ≥1), and 76 and 130 non-dominant, respectively (DIT <1). Regarding the dominant cities, Beijing, Shanghai and Guangzhou in the east are the top three cities in China but belong to different city classes in both networks. Although the three cities as national cores have the similar socio-economic performance in China, Beijing and Guangzhou are only in the first class of airline networks but Shanghai in the first class of both airline and HSR networks. This can be explained by two reasons:

Firstly, Beijing and Guangzhou's average distances to other cities (828 km and 1034 km) are larger than Shanghai's (723 km) in HSR networks, making air travel more attractive than HSR travel due to a shorter travel time.

Secondly, HSR networks in the densely populated YRD are much more developed (e.g. higher density and frequency of HSR networks) than in the Bohai Rim and the PRD, leading to more functional interactions of cities with Shanghai in the YRD than that with Beijing in the Bohai Rim and Guangzhou in the PRD by HSR networks.

Meanwhile, regarding the geographical location of Nanjing in the YRD region with completely developed HSR networks and its role of being a regional socio-economic core rather than a national one, it is not surprising to find that Nanjing is in the second class of HSR networks but the third class of air networks. Except to Shenzhen as a sub-provincial city in the east, Chongqing as a municipality city, Chengdu, Kunming, and Xi'an as provincial capitals in the west are in the second class of air networks, which reflects that major cities being as regional socio-economic cores in the west are competitive for the air travel than in the east.

In the third class of dominant cities, there are 25 HSR cities most of which are mainly regional capitals and economic centers in the middle and the east (i.g. Wuhan in Hubei province and Hangzhou in Zhejiang province) of the country. Only Chengdu and Chongqing are located in the west of China offering only connections between each other and not with the rest of the country. In the third class of dominant cities we also find 30 airline cities most of which are provincial capitals and economic centers in the middle and east, but include in comparison with HSR cities more provincial capital cities in the west, such as Urumchi, Guiyang, Nanning, Lanzhou and Yinchuan and typical tourism cities such as Sanya and Guilin.

In order to identify the different positions of a city in HSR and airline networks, we further identified the HSR and airline advantage cities by comparing the differences of city strength values (DIT) between HSR and airline networks among the 51 HSR-Airline cities. If one city's DIT value of HSR networks is larger than that of airline networks, it is considered as a HSR advantage city or otherwise an airline advantage city in Figure 4. Furthermore, Pearson's r (city strength correlation coefficient) and Spearman' rho (city rank correlation coefficient) test are used to identifying whether there is a direct correlation for 51 HSRAirline cities between HSR and airline networks.

The associations between the two networks for HSRAirline cities by the values of city strength and related rankings are statistically significant: Pearson's correlation coefficient is 0.871 ($p < 0.01$) and Spearman's rho is 0.788 ($p < 0.01$). This means that a city is dominant and highly ranked in one network should be the same in another network, thus it is necessary to not only take into account the large absolute value (DIT_HSR minus DIT_Airline >1 or DIT_Airline minus DIT_HSR>1) but more importantly the class changes to identify those outlier cities between two transportation networks.

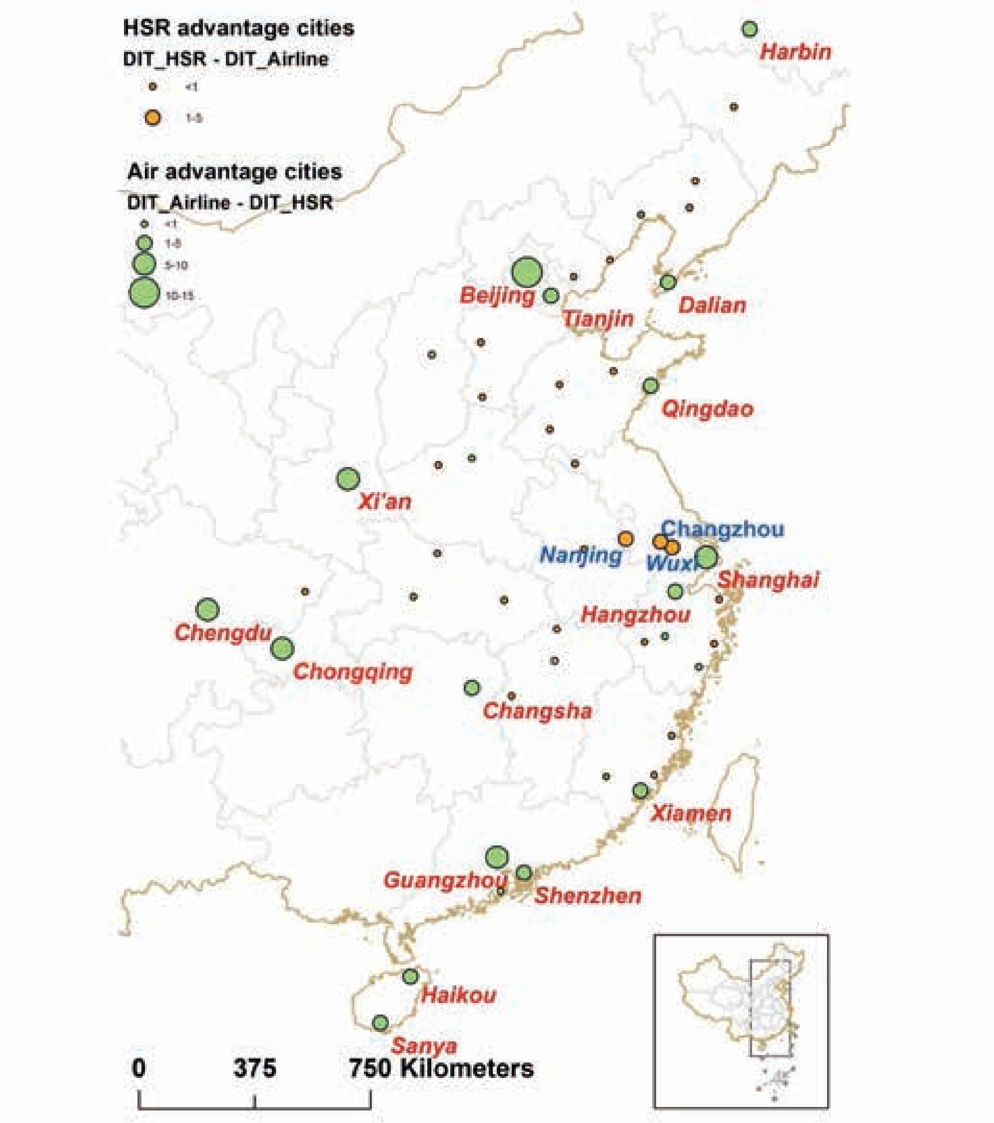

Figure 4. The comparison between HSR and Airline advantage cities.

With the difference value larger than 1, there are three HSR advantage cities (Nanjing, Wuxi and Changzhou) and 16 airline advantage cities (Beijing, Chengdu, Shanghai, Guangzhou, Xi'an, Chongqing, Shenzhen, Sanya, Haikou, Xiamen, Qingdao, Harbin, Dalian, Tianjin, Changsha, Hangzhou) in China. As to HSR advantage cities, Nanjing was upgraded from the third class of airline networks to the second class of HSR networks, Wuxi, Changzhou are from the fourth class to the third class. The three HSR advantage cities with more than 60 HSR connections to other cities are all major cities with a high number of GDP and populations, interacting strongly with each other within Jiangsu province by the Nanjing-Shanghai HSR route and with other cities out of Jiangsu province through the Shanghai-Hangzhou HSR route. Their HSR dominant positions not only reflect their important roles of serving as regional HSR hubs for short and medium distance travel, but also the intense interactions between them and adjacent cities which are facilitated by relatively more completed HSR networks in the YRD than any other regions.

In terms of airline advantage cities, except to Sanya and Haikou which are tourism cities in Hainan province[5], they are the major cities with high socio-economic performance and administrative levels mainly in the east and a few in the west. Among them, although there exist large differences between the city strength values in two transportation networks, Shanghai, Xiamen, Dalian, Changsha and Hangzhou did not have the class change. They are typical transport hub cities in specific regions with well-connected both HSR and airline networks, functionally interacting not only with distant cities far away but also adjacent cities within the regions to a certain extent. Therefore, in this case, although those cities are in the same class of both networks, their city strength is larger in airline networks than HSR networks because of some inbound airline passengers (or outbound airline passengers) transiting to/from other cities by HSR within the specific regions. For instance, despite some operational and administrative obstacles for the airline-HSR integration in Shanghai's Hongqiao Terminal (the best integrated transport hub in China), there are still a large amount of airline passengers transferring in Shanghai by HSR to adjacent cities in the YRD region (Givoni and Chen, 2017). This is also confirmed by aforementioned three HSR advantage cities within less than one hour HSR travel time with Shanghai. Different from those airline advantage cities without the class change, Beijing was upgraded from the second class of HSR networks to the first class of airline networks; Guangzhou and Shenzhen as the other two southern economic cores in Guangdong province were upgraded from the second and third class of HSR networks up to the first and second class of airline networks, respectively.

As mentioned before, due to its geographical location in the north with a larger average distance to other cities, being a national capital with the most airline connections, Beijing still heavily relies on the airline network for the interaction with other distant cities, which is also the case for Guangzhou and Shenzhen in the south. Chengdu and Chongqing in the south-west were upgraded from the third dominant class of HSR cities to the second dominant class of airline cities. However, different from the cases of Beijing, Guangzhou and Shenzhen, the weaker roles of Chengdu and Chongqing with fewer than three HSR connections to other cities are mainly a result of the uncompleted HSR construction between the middle and the west. Thus, their functional interactions with cities in the middle and even further to the east could be only facilitated by air networks.

Interestingly, Haikou and Sanya in Hainan province, and Harbin, and Tianjin in the north increase from the non-dominant class of HSR networks to the third dominant class of airline networks and Xi'an from the non-dominant class of HSR networks even to the second class of airline networks. Typically, Sanya and Haikou as two tourism cities in Hainan province are only served by the Sanya-Haikou HSR route; therefore, due to their isolated geographical locations in an island without direct ground transportation connections to the mainland of China, they have to resort to the airline transportation for carrying passengers to/from Hainan province, especially for leisure travel.

It is surprising that Tianjin as a municipality-level city, and Haerbin and Xi'an as sub-provincial and regional capital cities with large GDP and populations, are only dominant in airline rather than HSR networks. It could be that their regional integrations with adjacent cities are not as good as their interregional integrations with distant cities, which is reflected by both types of passenger flows from demand side. For instance, Tianjin's economic structures are less cooperative with other adjacent cities in the Bohai Rim (Yang, et al 2017). Therefore, it has to resort to the airline travel instead of HSR travel for the economic cooperation with other distant cities out of the Bohai Rim.

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[5] *Hainan province is an island separated from Mainland China by the Qiongzhou Strait with an average 30km width.*

4.1.2 Link strength

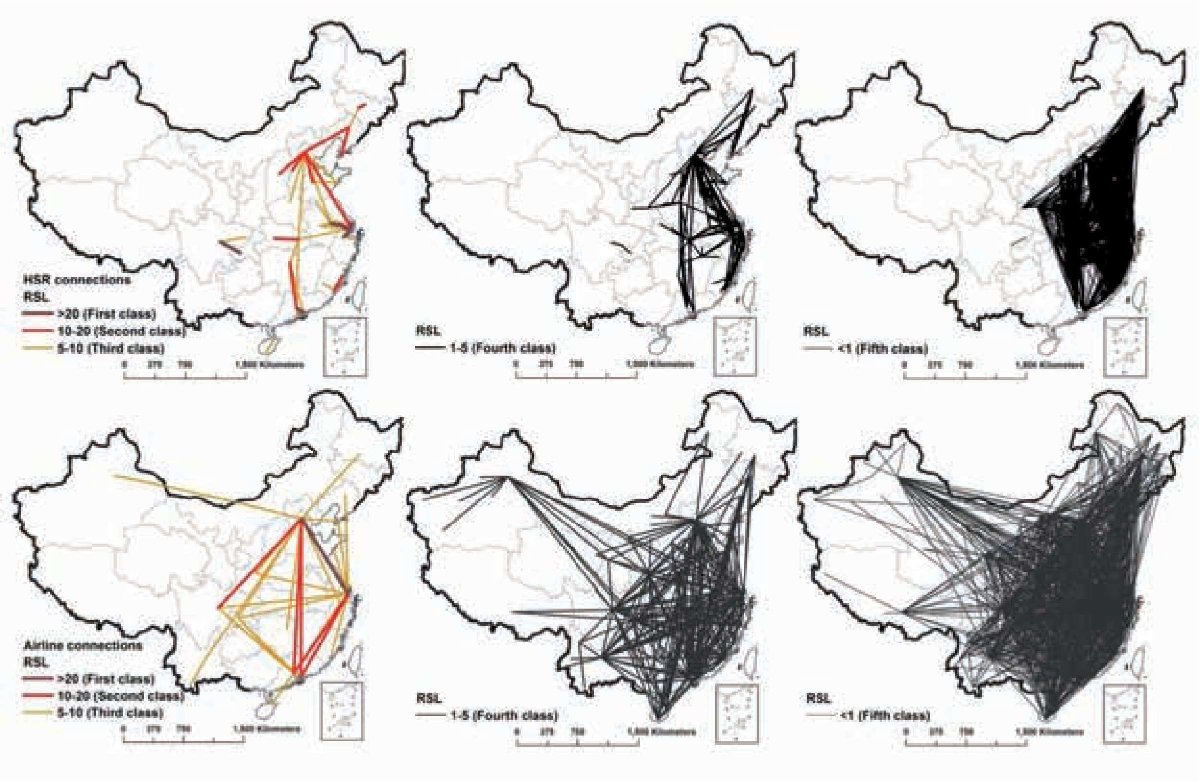


Figure 5. The geographical distribution of HSR and airline links.

Figure 5 shows the five classes of links in the HSR and airline networks. Regarding the first class, only the link Beijing-Shanghai connecting the Bohai Rim and the YRD region is in airline networks, while the links Guangzhou-Shenzhen in Guangdong province, Hangzhou-Shanghai, Suzhou-Shanghai, and NanjingShanghai in the YRD region, and Chengdu-Chongqing in the south-west are in HSR networks. It can be found that city ends in the first class are all national or regional socio-econoimic cores with quite high GDPs and populations. However, airline networks facilitated the interregional interaction between the national economic cores such as Beijing and Shanghai with a long geographical distance (1,092 km). In contrast HSR networks facilitate the regional interactions between regional economic cores with an average short distance (178 km), which can be understood as a consequence of the dense urban network in Eastern China. This typically reflects the primarily dominant position of each type of network for the inter-city connection at the national or regional scale, respectively.

In terms of the second class, besides to a few interregional links such as Beijing-Shanghai, GuangzhouChangsha and Beijing-Shenyang whose city ends are economic cores in different regions, there are more regional connections in HSR networks such as the links connecting Beijing to Shijiazhuang, Jinan and Taiyuan in the Bohai Rim and Shanghai to Wuxi and Changzhou in the YRD region; meanwhile, there are still only interregional connections for long distance travel in airline networks such as the links connecting Beijing to Guangzhou, Shenzhen and Chengdu, and the links connecting Shanghai to Guangzhou and Shenzhen. The Beijing-Shanghai link in the second class of HSR networks reflects that for interregional travel within a certain distance, HSR connections can compete with airline connections for the major city links.

As to the third class, HSR networks start to cover largely the inter-regional connections between capital cities within their respective regions such as Beijing-Nanjing and Guangzhou-Wuhan, while airline networks start to connect the national capital cities with high socio-economic performance and other regional capital cities with relatively low socio-economic performance such as the link Beijing-Urumchi, and further provide connection services between major and tourism cities within specific regions such as the link Kunming-Xishuangbanna in Yunan province. With regard to the fourth class, there are 219 links accounting for 14.9% of the total links in HSR networks in which the interactions between the middle and the east have increased to a large extent by HSR travel. Meanwhile, there are 155 links accounting for 16.9% of the total links in airline networks in which interactions between the west, the middle and the east parts of China have increased; the connections to cities in Xinjiang, Yunnan and Xizang provinces are only covered by airline networks. In the fifth (non-dominant) class, the airline connections have already covered the whole parts of China but with weaker intra-connections in the west than the middle and east, whereas the HSR connections still only cover the middle and east parts of China. This is likely a typical reflection of the core-periphery urban system in China where cities where cities in the middle and west are much reliable on the functional interactions with cities in the east by HSR and airline travel, respectively.

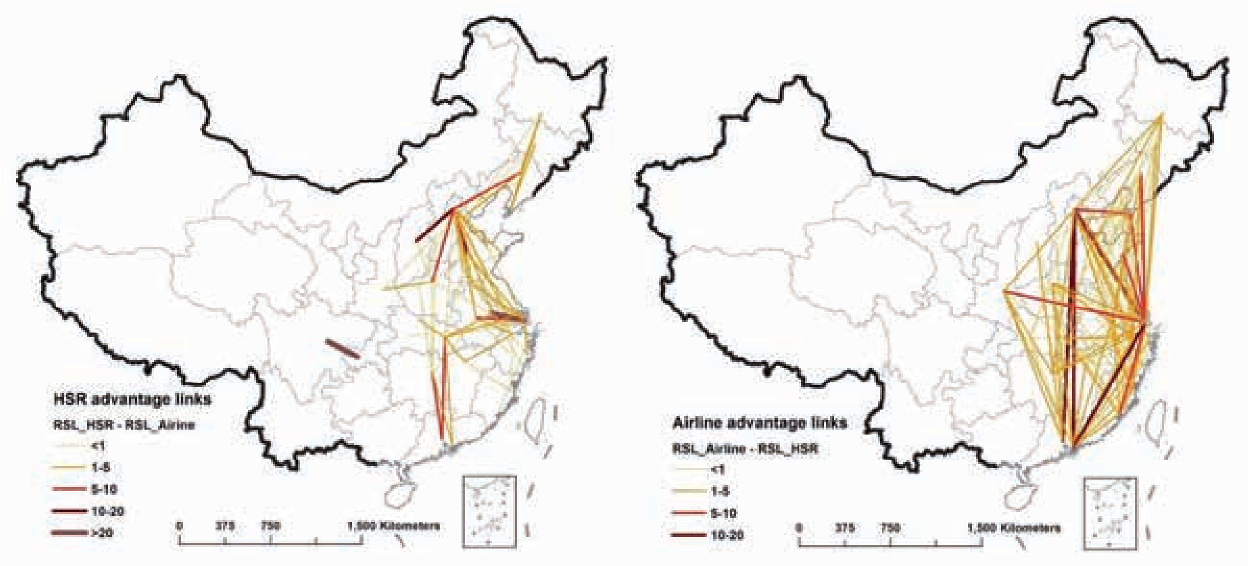


Figure 6. The comparison between HSR and airline advantage links.

We further identified the HSR and airline advantage links by comparing the differences of link strength values (RSL) between the HSR and airline network among 144 HSR-Airline city links. If one link's RSL value of HSR networks is larger than that of airline network, it is considered as a HSR advantage link or otherwise an airline advantage link in Figure 6. The associations between the two networks by the values of link strength and related rankings are statistically non-significant: Pearson's correlation coefficient is 0.167 ($p > 0.01$), and Spearman's rho is 0.123 ($p > 0.01$). This means that a city link with both HSR and airline connections, which is dominant in one transportation network, will be not dominant in another one. In Figure 8, it clearly shows that HSR advantage links normally connect the major cities with large populations and GDP in the specific region with a short travel distance. In contrast, airline advantage links connect the major cities with large populations and GDPs in different regions with a long travel distance. For example, both Chongqing-Chengdu and Shanghai-Nanjing were downgraded from the first class in the HSR networks to the fifth class in the airline networks, while Beijing-Shenzhen and ShanghaiShenzhen upgraded from the fifth class in HSR networks to the second class in airline networks. Therefore, it can be found that although for the city links with both HSR and airline connections, end nodes of links are mainly the major cities or hubs, whether they are dominant on HSR or airline networks are largely based on their geographical distances between the city ends.

4.1.3 City and link strength vs. attributes of urban systems

To interpret aforementioned results, we performed a multiple linear regression to investigate potential factors of both city and link strength

Table 2. Multiple regression on city strength

	DIT_HSR[a]	DIT_Airline[a]
	Standardized coefficients	Standardized coefficients
GDP per capita[a]	0.576***	0.184***
Average distance[a]	0.022	0.299***
Population[a]	0.414***	0.141***
Administrative level	0.185**	0.502***
Observations	105	168
Adjusted R-squared	0.689	0.665
* p<0.1 ** p<0.05 *** p<0.01		

[a] *Ln transformation.*

Table 2 shows results at the city level, it appears that GDP per capita and population of cities are the first and second most significant indicators for the city strength in HSR networks, compared to the administrative level of cities and the average distance to others in airline networks. Cities in HSR networks show higher elasticities of GDP per capita and population to the city strength than in airline networks, meaning that compared to airline travel, HSR travel is still mainly concerned about the connections to cities with higher socio-economic performance. The positive sign of the average distance to other cities in airline networks rather than in HSR networks indicates if one city is far away from others, the airline travel becomes a more suitable transportation alternative than the HSR travel for middle and long haul travel. Furthermore, the negative coefficients of the administrative level in both transportation networks indicate that in general the higher the city's position in the administrative hierarchy, the more likely passengers need to travel either to/from other cities. However, city strength is much sensitive to the administrative level in the airline network than in the HSR network. Therefore, it could expect both distance and administrative hierarchy more affect the city strength in airline than HSR networks.

Table 3. Multiple regression on link strength

	RSL_HSR[a]	RSL_Airline[a]
	Standardized coefficients	Standardized coefficients
Summed GDP per capital[a]	0.171***	0.198***
Summed population[a]	0.254***	0.027
Distance[a]	-0.571***	-0.081***
Summed administrative level	0.287***	0.457***
Observations	1675	1466
Adjusted R-squared	0.508	0.265
* p<.1 ** p<0.05 *** p<0.01"		

[a]*Ln transformation.*

Distance and summed administrative level are the most significant factors to the link strength in HSR and airline networks, respectively (Table 3).

It can be observed that the link strength has a much higher negative elasticity compared to the distance in HSR than in airline networks. This makes sense considering that with all other things being equal, the attractiveness of HSR services decreases when travel time increases (Givoni and Dobruszkes, 2013). If we eliminated the distance factor that can be considered as not being an attribute of cities, the model describes 19.7% and 25.9% of the variation in link strength in the HSR network and the airline network, respectively. This means that the geographical distance between cities in HSR networks has a larger impact on the link strength of city pairs than in airline networks. The reason could be that link strength is much more sensitive to the distance decay effect in HSR rather than airline networks and that the HSR travel is heavily restricted by the geographic condition of terrains. Furthermore, the negative sign of summed administrative level reflects that nodes of city links with a lower administrative level show low travel demand in between. However, the summed administrative level is much more elastic to the link strength in airline networks and thus proves that city nodes with a higher administrative level and being far away from each other tend to be served by airline travel. That indicates that public service obligations or any other governmental mechanism guarantees some decent level of airline service between distance cities.

4.2 Community structure

According to the HCA analysis, we visualized the communities of the HSR and airline network, respectively in Figure 7. The dendrograms of HCA of HSR and airline networks, which are presented in Appendix (A), can reflect the extent to which city nodes are bonded within each community. A shorter bracket and a lower position in the dendrogram trees mean a stronger relationship between a pair of cities in the subgroup.

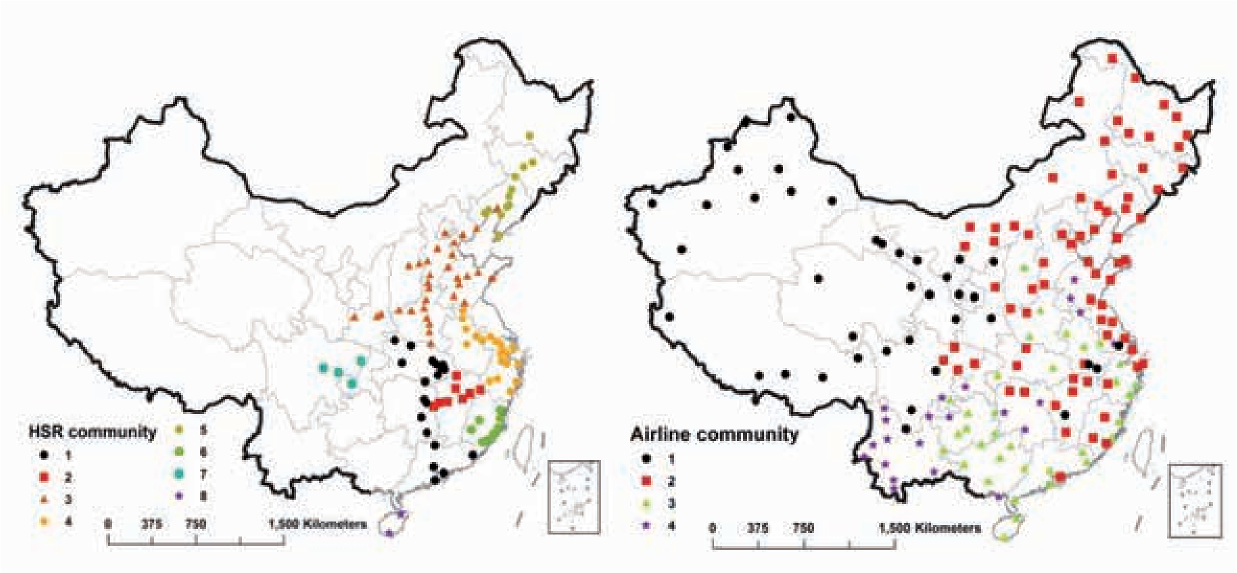


Figure 7. The spatial distribution of communities

In the HSR network, the modularity value is 0.58, and there exist eight subgroups with typical characteristics of geographical distributions in China, reflecting that the geographical proximity matters most in intercity relationships. For instance, in the YRD region, Shanghai services as the core and form the strongest bonds with Hangzhou along the Jinghu and the Shanghai-Hangzhou HSR routes. In the north-east with Liaoning, Jilin and Heilongjiang provinces, Jilin-Changchun and Dalian-Shenyang form strong bonds along the Jingha HSR routes covering the north-east regions. Besides, in Jiangxi and Fujian provinces, there are strong agglomeration effects within each province where Nanchang-Jiujiang and Fuzhou-Xiamen form the strongest bond, and then other peripheral prefecture-level cities are connected by parts of the Hukun HSR route and the southeast coastal HSR route within each province, respectively. Along the Wuhan-Guangzhou route connecting the middle and the southeast, cities are also clustered. Furthermore, two clusters are formed mainly due to the geographical isolation and less developed HSR network connections: Sanya and Haikou as mentioned before are isolated from the mainland of China. There is no direct HSR channel connecting the Hainan island to the mainland of China, which forces them to be a cluster connected by the Hainan HSR route. There exists another cluster in the southwest where Chengdu and Chongqing serve as the cores with limited connections with adjacent cities by parts of the Huhangrong HSR route due to a rather slow development of HSR networks up to 2013 in the southwest. In sum, HSR cities in the specific regions tend to be clustered with adjacent cities along the HSR routes.

In contrast, in the airline network, the modularity value is only 0.12 and accordingly there are four subgroups in the airline network without the obvious characteristics of the geographical cluster distribution in specific regions. For instance, in the airline transportation network, Shanghai and Shenzhen in the middle-east and the south-east forms the strongest bond and starts the first subgroup, and this subgroup grows with the addition of Xiamen and Tianjin. Then loosely connected cities in different parts of China then are added to enlarge the original group. Despite four subgroups in the dendrogram, they have not formed any major geographical clusters separately in specific regions due to the overlapping wide influence scopes of aviation centers.

5. Conclusions and discussions

This paper contributes to the current state of research, as it clearly reveals differential China's spatial structures of urban systems connected by its two high-speed transportation networks (HSR and airlines). To the best of our knowledge, this paper is the first study to use the actual O/D passenger flow data and compares the resulting configuration of the Chinese urban systems in tow type of high-speed transportation networks at the national scale. These urban systems are likely those of upper socialoccupational groups given the social filter that shapes the use of fast, long-distance transportation modes.

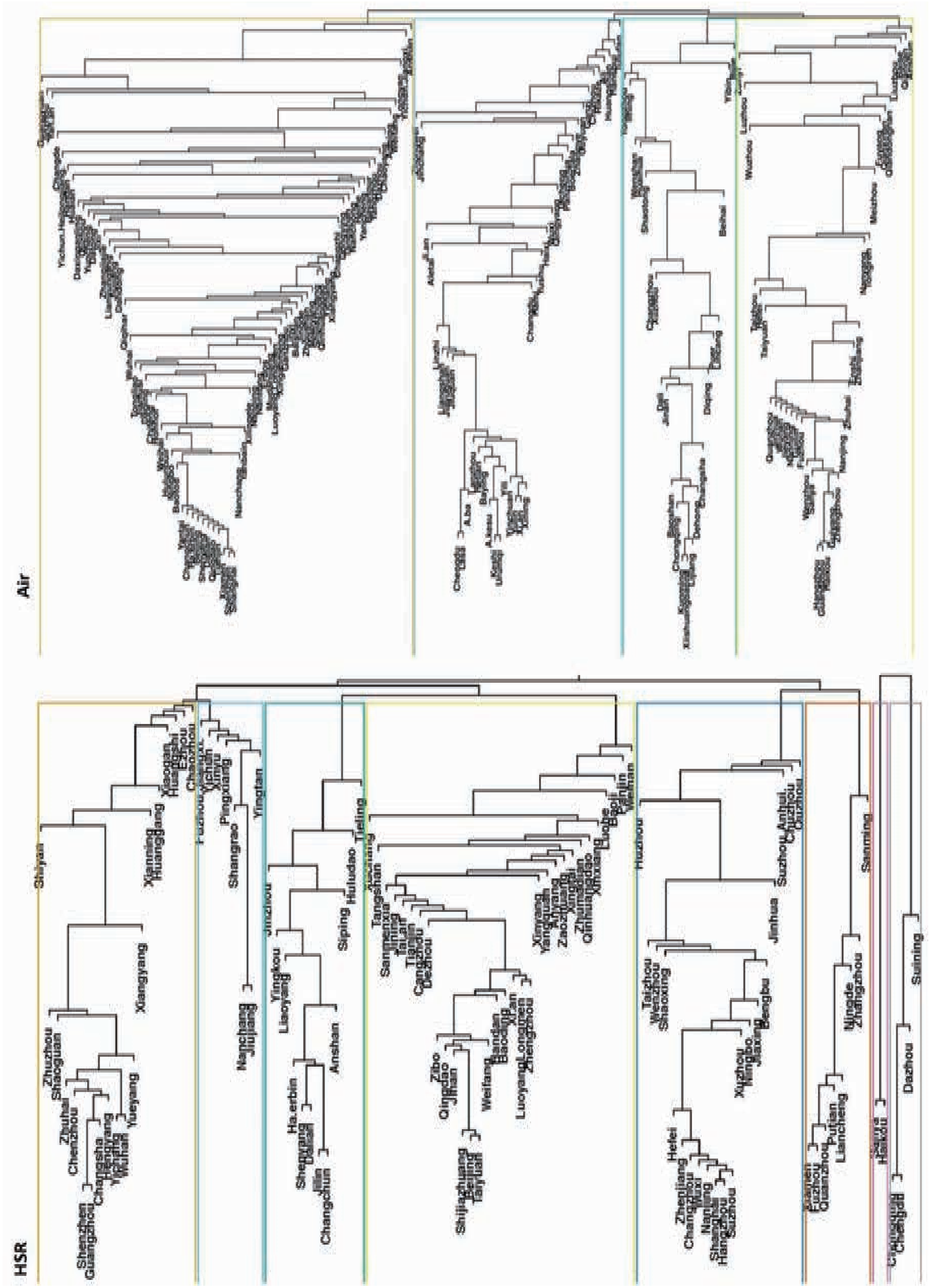
First, in terms of city strength, HSR dominant cities are mainly centralized in the middle and eastern parts of China, whereas airline dominant cities are evenly distributed over the whole China. This difference can be partly explained by the Chinese physical geography of the country: many cities are located far away from each other in the non-densely populated mountain areas of the west region that cannot be easily reached by surface HSR transportation, in contrast to the cities located in the densely populated plain areas of the east region. Movover, that difference can be further explained by that although both HSR and air passenger flows are constrained by the socio-economic performance of cities, the city strength in HSR networks tends to be more sensitive to socio-economic performance but less sensitive to administrative level of cities compared to air networks. This is largely a consequence of the relatively expensive investments in HSR networks that are socially and economically justifiable in high-density passenger volume areas compared to airline networks. In other words, not only HSR networks are not suitable for long-distance travel at the national scale, but also not viable for low-density passenger volume corridors, even though central governments can decide differently due to political reasons (de Rus and Nombela, 2007; Dobruszkes et al., 2017). Typically, in this case, remoter but higher ranked cities in the west part of China in 2013 are usually served by airline instead of HSR at the national scale, at least for the needs of the public authority's interactions between them and other dominant cities in the east from an administrative and governance perspective. Therefore, cities with high GDP and populations in the east are normally the core cities in both transportation networks, reflecting the inequitable development of urban systems. For instance, Beijing, Shanghai and Guangzhou as the top three cities in both HSR and airline networks reflect their national socio-economic importance in China's urban systems, which is similar to the finding of scheduled data in airline networks (Lin, 2012; Ma and Timberlake, 2008) but different from that in HSR networks (Jiao et al., 2017) where Nanjing instead of Guangzhou is in the top three. Regarding a much better socio-economic position of Guangzhou than Nanjing in China, logically Guangzhou should be more dominant than Nanjing at least in HSR networks from the perspective of demand side.

Second, in line with the former observation and explanation, the findings from the perspective of link strength further confirm that the regional connections between the middle and the east part have been largely facilitated by the HSR travel, but the interregional connections between the west and the east part still largely rely on the airline travel, consolidating a typical "flyover" effect in China as mentioned by (Jin et al., 2004). This is partly a reason that HSR travel is competitive for short and medium distance travel but airline travel competitive for medium and long distance travel, which is similar to the finding from World Bank (Zheng and Kahn, 2013). Moreover, although city nodes of links with better socioeconomic performance still induce a certain level of travel demand between both HSR and airline networks, the link strength in HSR networks is compared to airline networks highly sensitive to the geographical distance due to a severe distance decay effect, but less sensitive to administrative levels. Therefore, there exist stronger connections for city ends with a rather high administrative level and long distance in airline networks.

Third, in terms of community structure, compared to airline networks without an obvious pattern of clusters in specific regions, cities with dense populations and developed economies along with trunk HSR lines tend to be clustered in specific regions. Therefore, it is worth noting that agglomeration economies of urban systems could be facilitated by HSR networks, whereas airline networks relatively contribute to a more balanced urban development by increasing interactions especially between cities with lower socio-economic performance in the west and ones with higher socio-economic performance in the east.

This paper opens several research perspectives. First, because long-distance transport networks evolve over time and shape the demand to some extent, it will be of interest to replicate our analyses for several years. Indeed, the total HSR length will extend from 19,100 km in 2016 to 30,000 km in 2020 in comparison to the total number of airports from 216 to 260 (NDRC, 2016), which means that the HSR development will be in a faster growth rate especially in the western part of China after 2013. On the airline side, the expansion of low-cost airlines in China (Jiang et al., 2017), even though at a controlled rate, could also affect the pattern of domestic intercity travel. Future research after a fully complete construction of the HSR and mature airline networks could thus shed light on updated China's urban systems, especially regarding that new HSR developments in western China could play an important role in bridging China and Euro-Asian urban systems by the Belt and Road Initiatives. In addition, future research could better consider that HSR and airline networks are highly related to the economic process of cities nodes. Therefore, comparisons of HSR and airline passenger flows with other socio-economic intercity flows could more clearly illustrate the relationship between the economic networks and highspeed transportation networks. Finally, since HSR and airline travel are mostly due to upper socialoccupational groups, it is of interest to expand our work with intercity travel made by traditional rail services and by road. This would arguably diversify travelers' social –and thus spatial– patterns. The resulting urban system would thus be more comprehensive, and comparison of urban systems rendered by traditional/slower vs. modern/faster transportation modes would be full of lessons to be learnt.

6. Appendix A. Dendrogram trees for the HSR and airline networks.



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