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Comparing China's urban systems in high-speed railway and airline networks

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ABSTRACT

Although the Chinese high-speed railway (HSR) entered the transportation market at a late stage in 2003, its networks have become the world's largest and are currently even growing faster than airline networks. Using the 2013 origin/destination (O/D) passenger flow data instead of commonly used scheduled data, we compare the spatial configurations of the Chinese national urban system in both high-speed railway and airline networks. The results show that HSR-dominant cities and links are located mainly in the middle and eastern parts of China, offering regional connections, whereas air-dominant cities and links are evenly distributed across the whole of China and predominantly offer interregional connections. This is mainly because HSR networks are more focused on connections to cities with high socio-economic performance and are more restricted by the geographical distance between linked cities than the airline networks. Furthermore, HSR networks promote agglomeration economies within cities located along the trunk lines in specific regions, whereas airline networks contribute to more balanced urban development in China. These dimensions indicate that the configuration of urban systems in HSR networks differ largely from that of air networks when measured in terms of passenger flows.

1. Introduction

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

Given their important role in linking urban areas,the development of airlines and HSR has been supported with substantial capital and infrastructure investment in China. The development of both systems has been very rapid. The global ranking of China's airline transportation networks, based on scheduled seats, was 37th in 1978, but rose to second place after 2005. The number of civil-certificated schedule airports 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 transportation system (Fu et al., 2012; NDRC, 2016). Although China's HSR networks entered the transportation market at a late stage in 2003, they have become the largest in the world (a total of 19,000 km by the end of 2015, accounting for over 60% of the global figure), even though HSR length per capita is less spectacular due to the size of the country (Delaplace and Dobruszkes, 2016). This network served > 70% of the population and the cities involved account for 80% of GDP (Wang et al., 2015; NDRC, 2016). It should be noticed that, in 2016 the mode shares of HSR and airlines are 6.4% and 2.6%, respectively, compared to the 81.2% and 1.4% of highways and waterways (NBSC, 2017). These investments have stimulated the integration of the national urban network (Ng and Wang, 2012) and are seen as part of its future integration with Euro-Asian

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urban systems via the by the Belt and Road Initiative (BRI) (Liu and Dunford, 2016).[1]

A great deal of the existing literature exploring the functional relationships within urban systems has relied upon scheduled seat airline data, measuring the capacity of aircraft movements across the world (Smith and Timberlake, 2001; Derudder and Witlox, 2005; Derudder and Witlox, 2009; Van Nuffel et al., 2010). However, HSR travel has received less attention, and also the few available studies on the functional relationships within urban systems in Europe (Hall and Pain, 2006) and China (Zhang et al., 2016) at the regional and sub-regional levels are based on time schedule data not a measure of capacity. In most of the research carried out to date, airline and HSR travel have been studied separately. One exception is the study by Xiao et al. (2013), in which passenger data of conventional railways and airlines are used to estimate a reversed gravity model to identify the attractiveness of a limited number of cities in China. Several studies have used the supply and demand side of airline flow data to understand HSR's impacts on domestic aviation in China (Chen, 2017; Wang et al., 2017). To the best of our knowledge, no study has compared the role of high-speed transportation networks (i.e. HSR and airlines) on one national urban system using the same type of passenger flow data. Our research tries to fill this gap. Thus, the key research question in this paper is: To what extent does the configuration of Chinese cities served by HSR differ from those served by airlines? This is of particular interest for two reasons. First, as we argue in the next section, the understanding of the functional relationships between the cities in an urban system is better reflected by passenger flow data(i.e. the demand side) than by timetable information (i.e. the supply side) (Yang et al., 2018). Second, both HSR and airlines in China mainly carry people from the middle and upper-middle income classes, that is, social groups with 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 each the high-speed transportation network will provide precise insight on the working of these activities and so add to our understanding of Chinese regional economic development. The insight on each network will be valuable in future high-speed transportation and urban systems 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, we discuss the results of our analyses, which consist of a general overview of HSR and airline passenger flows on a national scale. This section is followed by a comparison between them. The final section concludes the paper and offers an overview on future research issues.

2. Literature review

To understand the functional relationships between cities, studies on transportation networks have explored the space of flows of information, people and capital proposed by Castells (1996) at different spatial scales. The “space of flows” of people incorporates three layers. The first layer is the infrastructure providing 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 the directional movements of each function (Derudder and Taylor, 2005).

Two types of empirical approaches have emerged to assess the flows between 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, there have been strong criticisms of 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 external interaction (Robinson, 2005), which means the derived linkages of people, information, and service from node attributes cannot reflect the direction in which flows are actually produced by people or the extent of these flows (Neal, 2010). Therefore, a better approach is based on actual physical 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 network structure of world cities on a global scale (e.g. Smith and Timberlake, 2001; Choi et al., 2006; Derudder and 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 HSR time schedule data to approximate actual passenger flows to uncover the relationships among cities in the Yangzi River Delta (YRD) region in China, Hall and Pain (2006) used scheduled train services to identify polycentric urban regions in Europe, and Jiao et al. (2017) used scheduled train services to explore the impacts of HSR on the city network of China.

However, this form of 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 seat-kms). The rationale for supply-side data is that carriers' strategies are expected to draw passengers according to existing and potential interactions between places served. However, the supply is by definition larger or equal to the demand satisfied by each transportation mode, so at best it can be considered just a proxy for the actual flows of people (Neal, 2014).[2] Second, supply or demand data are usually given regarding the individual legs of trips rather than for 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 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; Derudder and Witlox, 2005). Some researchers have addressed this issue regarding airline travel by using the so-called Marketing Information Data Transfer (MIDT) dataset, which is based on the actual origins/destinations of airline travellers (Derudder et al., 2007). However, information is based on bookings made through global distribution systems (GDS). This means that those travellers who book directly on airlines' websites are not included, which could arguably lead to biases, for instance, an underestimation of people flying on low-cost airlines.[3]

Finally, HSR timetables are difficult to convert to the number of seats available 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 pursues a high-frequency strategy (that is, operating frequent services but likely with less capacity per train), the estimated interactions between cities derived from HSR frequency would be biased. Second, one still needs to consider that most high-speed trains call at several intermediate stations. This involves uncertainties about 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

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[1] China's BRI is a call for an open and inclusive (mutually beneficial) model of cooperative economic, political and cultural exchange (globalization) that draws on the deep-seated meanings of the ancient Silk Roads.

[2] The number of passengers carried by transportation modes between cities is basically equal to or smaller than the number of seats.

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

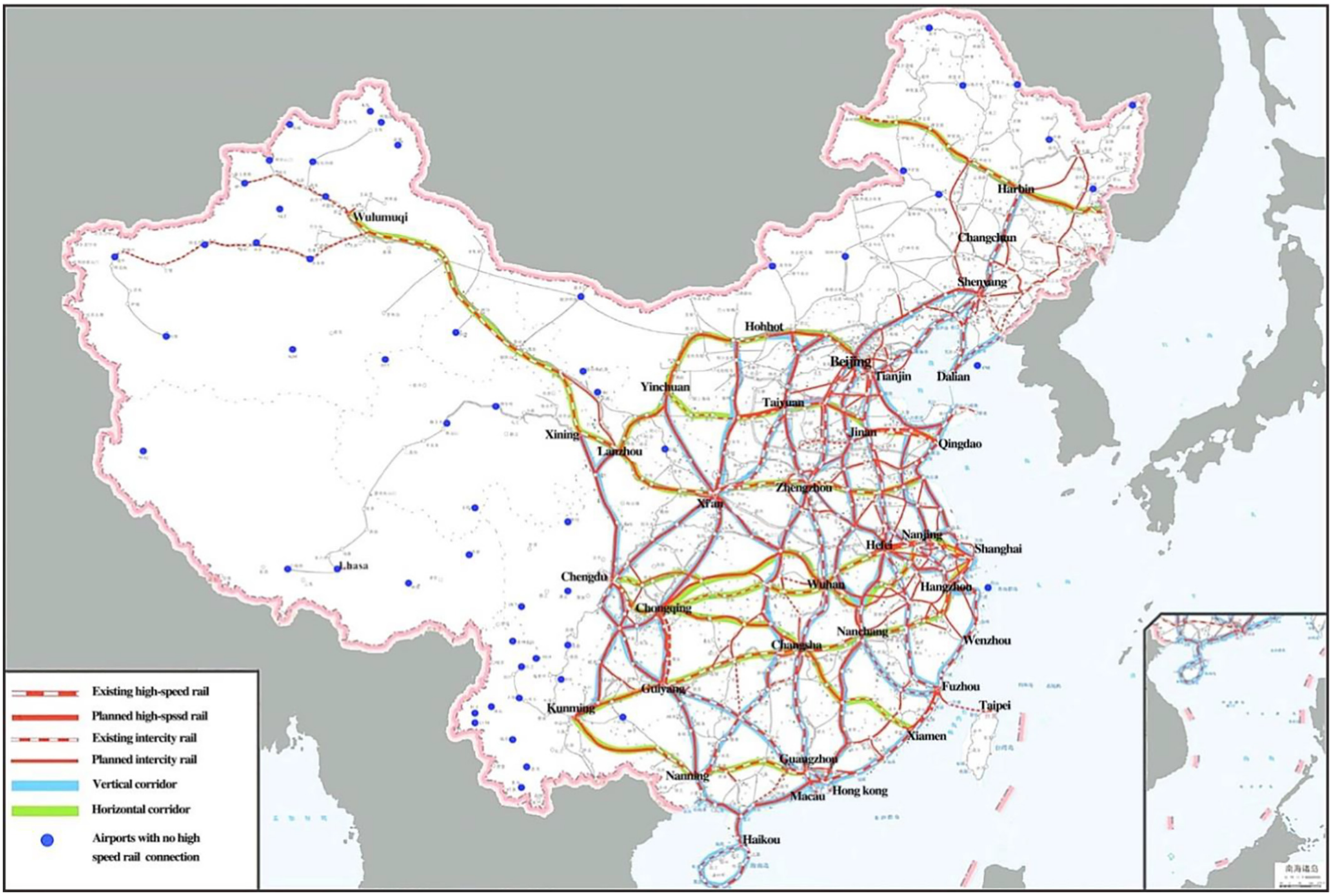

Fig. 1. HSR and airport planning in China.
Adapted from NDRC (2016).

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. (2018) found that details of train schedules can underestimate the rank of major cities in the urban system, especially in China, with its large capacity on trains running between major-tier cities. Because of 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 not fully available to scholars. Commercial privacy and confidentiality supersede academic purposes, even in China's strictly controlled railway sector (Liu et al., 2015).

In summary, the current research on airline and HSR networks, based largely on time schedule data instead of the actual number of passengers carried can lead to a misunderstanding of functional links within an urban system. Furthermore, the world city research using airline data and regional urban system research using HSR data do not intersect, even though they may include a limited number of the same cities. What is missing is a comparison of the roles of HSR and airlines on the same national urban system. Our research tries to fill this gap by using both HSR and airline O/D passenger flows within the national urban system of China.

3. Methodology

3.1. Data description

In this study, cities are the nodes in the transportation networks (Fig. 1). Statistical data series in China recognises four levels of cities: municipalities, sub-provincial and provincial capital cities, prefecture-level cities, and county-level cities (Ma, 2005). If cities had multiple HSR stations and/or 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 all stations and airports in the two urban areas.

The relationship between cities is operationalized as the actual number of HSR and airline passengers travelling between cities. The HSR passenger matrix was created from a collection of the Transportation Bureau of the China Railway Corporation, which included the total numbers of D train and G train HSR O/D passengers travelling between pairs of cities.[4] The data cover the 105 existing HSR cities, including 4 municipality-level, 21 sub-provincial/provincial capital-level and 80 prefecture-level cities and refer to 1675 city links with passenger flow larger than zero in 2013. This represents over 436 million passengers and with an average number of 260,298 passengers per city pair). The airline passenger matrix was created from a collection by the Civil Aviation Administration of China and includes the total number of O/D air passengers travelling between pairs of cities. The data cover the 168 airport cities (four municipality-level, 32 sub-provincial/provincial capital-level and 132 prefecture-level cities) and 1467 links (passenger flow larger than 0) in China in 2013 (representing over 306 million passengers with an average number of 208,588 passengers per city pair). Both HSR and airline O/D passenger flow data are aggregated and do not include any personal information such as age, gender, and income. In these data bases there were 51 cities with both HSR and airport terminals and 144 city pairs with both

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[4] According to China's classification of HSR services, these are D and G trains.

HSR and airline connections.[5] The cities used in the analysis and details of current and planned rail connections along with cities that have no current HSR link are shown in Fig. 1.

Airline and HSR services do not account for all medium- and long-distance travel within China. Indeed, there is evidence that the poor and even part of the middle class have much less access to airlines and HSR due to their relatively high cost of travel compared to conventional railways (Delaplace and Dobruszkes, 2015; Wang et al., 2013; Liu and Kesteloot, 2015). Furthermore, various cities are not served by HSR or air services, so our research does not capture the full set of functional interactions between cities. Instead, it focuses on a major element of the urban system being the mobilities of the upper social-occupational groups (business activities, government officials, premium tourism, or VFR [visiting friends and relatives] travel).

3.2. Analytical framework

3.2.1. Measures of city centrality and link connectivity

To identify the structural characteristics of the urban system as manifested by airline and HSR passenger flows, we need to establish the urban hierarchical structure based on measures of city centrality and connectivity in the transportation network. We create these measures by adapting the approach presented in Limtanakool et al. (2007) and Van Nuffel et al. (2010).

The measure of city centrality is as follows:

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

where we define DIT_i as city centrality, indicating the relative strength of city i in the national transportation network. T_i is the total number of passengers associated with city i, and $i \neq j$. 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.

The measure of link connectivity is as follows:

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

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 $i \neq j$. 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 clearly understand their strength values, the RSL value is multiplied by 1000 (Derudder and Witlox, 2009). To compare the different ranks of cities and city pairs in the two transportation networks, according to Wang and Jing (2017), we create three categories of cities in terms of the city-centrality index, and four categories of city pairs in terms of the link connectivity index. The values used are shown in Table 1. This classification simplified the comparison of each city and city pair's ranking in the two networks.

We further performed a multiple linear regression to investigate the differential impacts of a set of attributes of the urban system on the two strength measures. Following the existing literature, in Table 2 we included a mix of geographic, social, economic, and political attributes of each city as potential covariates. We acknowledge that such regression should control for price effects, considering that intermodal competition is affected by fares (Zhang et al., 2017). In 2013, airline fares were already freely set by the airlines, at least to some extent. As a result, fares can fluctuate subject to various factors, including date of travel and date of purchase, so ex-post data on actual fares paid by the travellers were needed. Unfortunately, such data were not available to us.

Table 1
Categories of cities based on values of indices.

Index	Rank of city			
	First	Second	Third	Fourth
City centrality (DIT)	> 10	5–9.9	1–4.5	
Link connectivity (RSL ∗ 1000)	> 20	10–19.9	5–9,9	1–4.5

3.2.2. Hierarchical cluster analysis (HCA)

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

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

We define Q as the modularity value; the higher the value of Q, the stronger the community structure. 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, and d_m is the total number of cities in community m.

4. Results

4.1. Descriptive analysis

In this part, we first describe competitive relationship between HSR and airlines, especially regarding thresholds of distances and the scale of city-populations that utilise services available between city pairs. The bottom half of Fig. 2 indicates there are three competitive relationships between HSR and airlines (summarized in Table 3), a finding is similar to the finding of World Bank that, generally, HSR has an advantage over airline travel for journeys up to 3 h or 750 km (Zheng and Kahn, 2013). The top half of Fig. 2 indicates that city populations of the links have little effect on the competitive position of HSR and airlines.

4.2. The comparison of city centrality for HSR and airline networks

4.2.1. City centrality

The initial step here was to use, Pearson's r (correlation coefficient) and Spearman's rho (city rank correlation coefficient) test to identify whether there is a direct correlation in index score at these cities. The associations between the two networks 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 that is dominant and highly ranked in one network is likely to have the same rank in the other network. However that general association might mask important individual city differences, so the anaysis explored differences in absolute values of the index at each city. It identified two groups of cities, one where DIT (HSR) minus DIT (Airline) > 1 or DIT (Airline) minus DIT (HSR) > 1) and then looked at the rank of the cities involved.

As shown in Fig. 3, 29 out of 105 HSR cities and 37 out of 168 airline cities have a centrality > 1 and so are seen as dominant transport centres. Among these dominant cities, Beijing, Shanghai, and Guangzhou in the east are the top three cities in China, not surprising

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[5] National HSR passenger flow data are rarely accessible for researchers in China and the project's access was limited to 2013 data.

Table 2
Independent variables used in for regression analysis.

Independent variables	Explanation	Source	Mean_HSR (SD_HSR)	Mean_Airline (SD_Airline)
City centrality				
GDP per (million yuan)	Gross domestic product per capita for a city in 2013	Chinese urban statistical yearbooks 2014	3712.4 (3989.6)	2549.6 (3431.5)
Population (inhabitants)	Urban population of a city in 2013		578.5 (428.7)	452.2 (402.9)
Average distance (km)	The average distance from one city to all other cities connected by HSR or airline networks in 2013	Calculated by authors from GIS	551.4 (175.2)	914.2 (320.8)
Administrative level	Hierarchical administrative level of cities in China (scored) 3 = Municipal level city 2 = Sub-provincial/ regional capital level city 1 = Prefecture city	Ma (2005)	2.7 (0.5)	2.8 (0.5)
Link connectivity				
Summed GDP per (million yuan)	Summed gross domestic product per capita for each city pair of origin and destination in 2013	Calculated by authors	9361.4 (6604.1)	12,145.1 (6923.8)
Summed population (inhabitants)	Summed population for each city pair of origin and destination in 2013		1264.0 (607.5)	1489.3 (854.0)
Distance (km)[a]	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 in 2013		5.3 (0.8)	4.5 (0.7)

[a] Direct geographical distance instead of summed average distance is a better indicator for the link attribute.

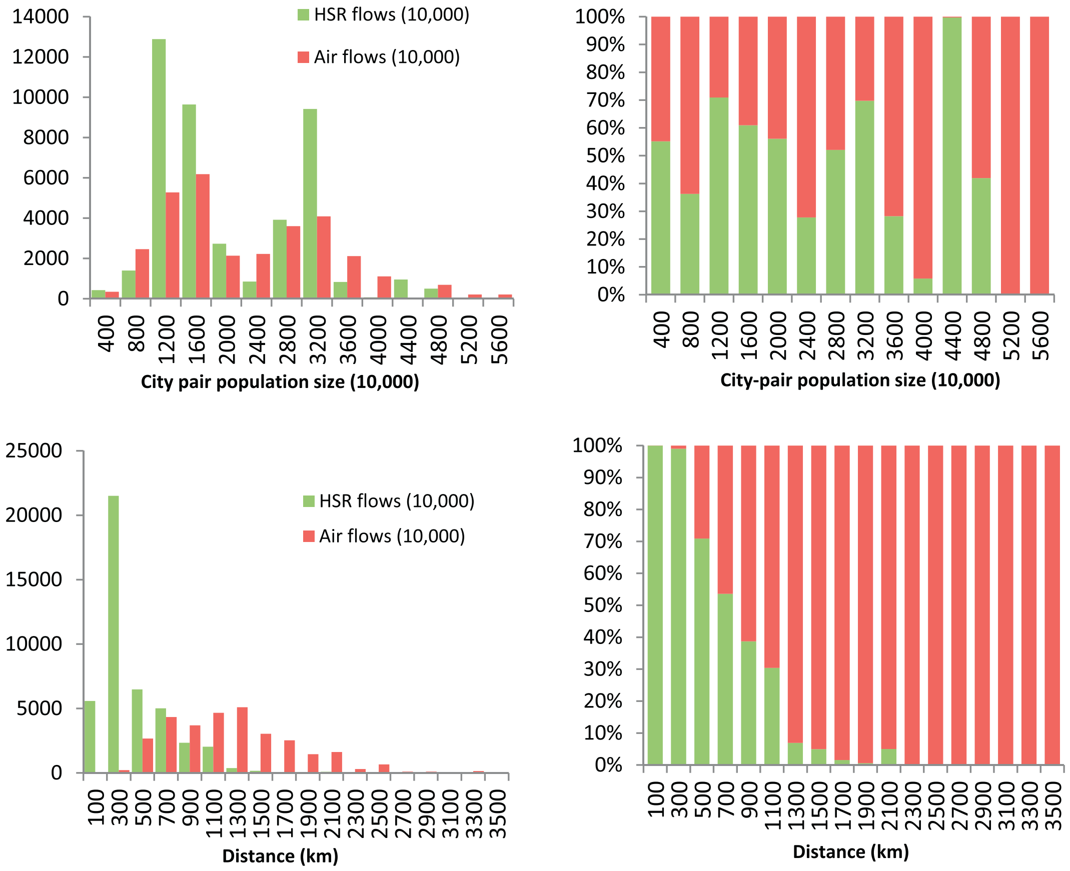

Fig. 2. Absolute number of passengers and modal shares by city size and distance.

given their similar socio-economic roles in the Chinese economy. However they are in different ranks for HSR and airline categories on their centrality scores. Beijing and Guangzhou are only in the first rank for airline networks, but Shanghai is in the first rank for both airline and HSR networks. There are two reasons for this result. First, in HSR networks, Beijing and Guangzhou ‘s average distances to other cities (828 km and 1034 km) are larger than Shanghai's (723 km), making airline travel more attractive than HSR travel from these cities. Second, the HSR network in the densely populated YRD is much more developed (with higher density of lines and greater train frequency) than in the Bohai Rim[6] and Pearl River Delta (PRD). As a result, there are more

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[6] Bohai Rim is a northeast costal region in China which includes Beijing, Tianjin,

Table 3
The market share of passenger transport by HSR vs by Airline in China, 2013.

Distance	Market share: HSR vs Airlines
700 km	Dominated by HSR
700–1100 km	Shared between HSR and Air
> 1100 km	Dominated by Airlines

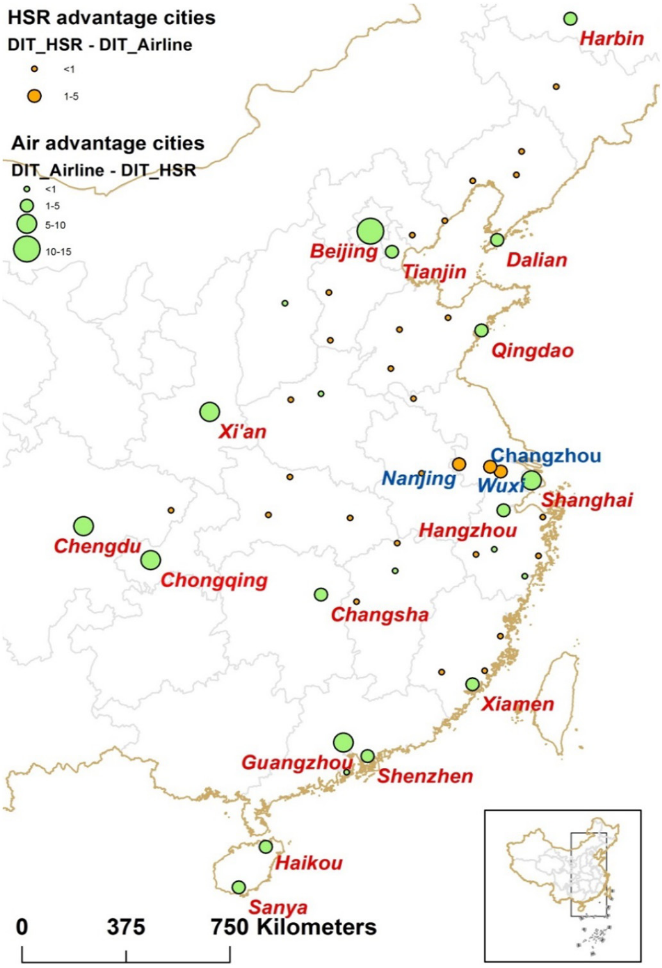

Fig. 4. Cites with an advantage on the HSR and airline centrality Index.

functional interactions between cities and Shanghai in the YRD than between Beijing in the Bohai Rim and Guangzhou in the PRD. The effect of the development of the YRD is also felt in Nanjing which is a third rank airline network city, but a second rank HSR city. It can be seen as a regional socio-economic city well served by HSR networks in the YRD region. Elsewhere Chongqing, Chengdu, Kunming, and Xi'an are second ranked in airline networks, indicating that major regional socio-economic cities in the west depend on airline travel more than those in the east. Surprisingly Shenzhen, as a sub-provincial city in the east is not in the second rank in airline networks, perhaps because of the influence of Guangzhou on its airline transportation activity. In the third rank of dominant cities, there are 25 HSR cities, most of which are mainly regional capitals and economic centers in the middle and east (e.g. Wuhan in Hubei province and Hangzhou in Zhejiang province) of the country Chengdu and Chongqing are also thrid ranked HSR cities largely because they have most connections between each other and not with the rest of the country. There are 30 third rank airline cities, most of which are provincial capitals and economic centers in the middle and east, but in contrast to the HSR ranking this group includes more provincial capital cities in the west, such as Urumchi, Guiyang, Nanning, Lanzhou, and Yinchuan and typical tourism cities, such as Sanya and Guilin.

To further analyse the different ranking of cities in HSR and airline networks, we compared the differences in city centrality values (DIT) for HSR and airline for the 51 HSR-airline cities. We find one group of cities have an advantage in HSR (their HSR index is larger than their airline index), and a second group where there is an advantage on the airline index. They are shown in Fig. 4.

Considering just those cases where the difference in the centrality index value is larger than 1, there are three HSR advantage cities Nanjing, Wuxi, and Changzhou. These three major cities have a high GDP and have > 60 HSR connections to other cities, interacting strongly with each other within Jiangsu province through the Nanjing-Shanghai HSR route and with other cities out of Jiangsu province through the Shanghai-Hangzhou HSR route. Their dominant HSR positions reflect their important role as regional HSR hubs for short- and medium-distance travel and the intense interactions between them and adjacent cities, which are facilitated by more dense network of HSR lines in the YRD. Looking at the cities in more detail shows their air network ranking is very low (either third or fourth class) confirming their special roles as HSR cities.

There were 16 airline advantage cities where the the difference in

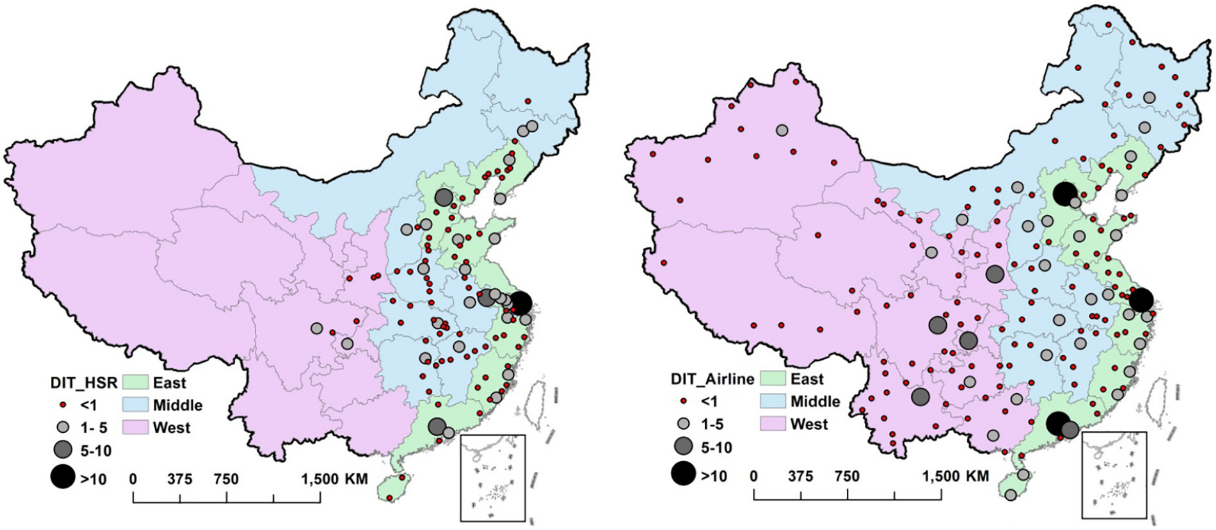

Fig. 3. The city centrality of HSR (left) and airline (right) networks. (The division between the west, middle, and east is based on NBSC (2011).)

the centrality index value is larger than 1. These are Beijing, Chengdu, Shanghai, Guangzhou, Xi'an, Chongqing, Shenzhen, Sanya, Haikou, Xiamen, Qingdao, Harbin, Dalian, Tianjin, Changsha, and Hangzhou. Except for Sanya and Haikou, (which are located in Hainan province, an island separated from Mainland China, and so airline travel dependent) these are major cities with high socio-economic performance and administrative levels, located mainly in the east with just a few in the west.

It is important to note that several of these air advantage cities are highly ranked as HSR cities, with Shanghai, Xiamen, Dalian, Changsha, and Hangzhou ranked in the same class on the index for both HSR and airline networks. These cities are typically multimodal transportation hubs that still offer strong HSR and airline connections. For instance, despite some operational and administrative obstacles to the integration of airline-HSR in Shanghai's Hongqiao Terminal (the best integrated transport hub in China), a large number of airline passengers transfer in Shanghai through HSR to adjacent cities in the YRD region (Givoni and Chen, 2017). Elsewhere among the major cities Beijing, Guangzhou, and Shenzhen tend to have different HSR and airline ranks reflecting the distances travelled and less well developed regional HSR systems, as discussed earlier. A similar difference applies to Chengdu, and Chongqing in the southwest where the lower HSR index is mainly the result of the uncompleted HSR construction between the middle of the country and the west so national interactions with cities in central and eastern regions are largely by airline networks.

A similar situation can be seen for Harbin and Tianjin in the north and Xi'an. It is surprising that Tianjin as a municipality-level city and Harbin and Xi'an as sub-provincial and regional capital cities with large GDP and populations are only dominant on the airline index rather than for HSR networks. It could be that their regional integrations with adjacent cities are not as good as their inter-regional integrations with distant cities, which is reflected by both types of passenger flows from the demand side. For instance, Tianjin's economic structures are not well linked with other adjacent cities in the Bohai Rim (Yang et al., 2018). Therefore, it must rely on airline travel instead of HSR travel for economic cooperation with the rest of China.

4.2.2. Link connectivity

The associations between the two networks on the link connectivity index were shown to be 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 a city link that is dominant in one transportation network will be not dominant in another. That is perhaps not surprising as it has been shown that these two modes operate over very different distances. To consider the situation at individual cities Fig. 5 shows the four classes of links in the HSR and airline networks. Only the Beijing-Shanghai link, connecting the Bohai Rim and the YRD region, is identified in the first rank of airline networks, while the Guangzhou-Shenzhen, Hangzhou-Shanghai, Suzhou-Shanghai, Nanjing-Shanghai and the Chengdu-Chongqing are all first class HSR links. This suggests the major airline networks have facilitate inter-regional interaction between national economic cores such as Beijing and Shanghai over a long geographical distance (1092 km) while major HSR networks facilitate regional interactions between economic cores with an average short distance (178 km), reflecting the dense urban network in Eastern China.

Second ranked air links involve passenger movement on long-distance inter-regional connections between Beijing and Guangzhou, Shenzhen and Chengdu, and links connecting Shanghai to Guangzhou and Shenzhen. In HSR network, the second ranks involve inter regional movement between Beijing-Shanghai, Guangzhou-Changsha, and Beijing-Shenyang, as well as intra-regional connections such as Beijing to Shijiazhuang, Jinan and Taiyuan in the Bohai Rim, and Shanghai to Wuxi and Changzhou in the YRD region. It is significant that the long distance Beijing-Shanghai HSR link is classified as thesecond class, showing the depth and breadth of the connections between those two cities is expressed in the competitive relationship between HSR and airlines for passengers travelling.

As for the third class on the rank index, airline links have connections from prominent national cities with high socio-economic performance to regional capitals with relatively low socio-economic performance, such as Beijing-Urumchi, and also provide connections between regional cities and tourism destinations within specific regions such as the Kunming-Xishuangbanna link in Yunan province. HSR links cover the inter-regional connections between regional capitals and those within their respective regions, such as Beijing-Nanjing and Guangzhou-Wuhan. With regard to the fourth class of links, 155 links account for 16.9% of the total links in airline networks which includes interactions between the west, the middle, and eastern parts of China, for example the connections to cities in Xinjiang, Yunnan, and Xizang provinces. For the HSR travel, there are 219 connections accounting for 14.9% of the total links in HSR networks and include interactions between cities in the middle and east. The location of these cities and their connections is a typical reflection of the core-periphery urban system in China where cities in the middle and west rely heavily on functional interactions with cities in the east through HSR and airline travel, respectively.

As same as explained above for City centrality, we identified “advantage linkss” where HSR or Airline connectivity index were large. Fig. 6 clearly shows that HSR advantage links are recorded in the eastern region on links that connect smaller cities with the major cities that have large populations and GDP, often over a short travel distance. In contrast, airline advantage links connect the major cities with large populations and GDPs in different regions, over longer travel distance. The index recorded for HSR and airline links at individual cities are often very different. So for example, both Chongqing-Chengdu and Shanghai-Nanjing are in the first class of HSR networks but in the fifth class of airline networks, while Beijing-Shenzhen and Shanghai-Shenzhen were in the fifth class of HSR networks but in the second class of airline networks. As noted earlier these outcomes reflect the distances between these cities.

4.2.3. The influence of urban system attributes on city centrality and link connectivity indices

To provide deeper insight on the aforementioned results, we used the two indices as dependent variables in two multiple linear regression models to investigate the differential impacts of attributes of urban systems specified as independent variables in the analytical framework.

Table 4 shows results at the city level. It appears that GDP per capita and the population of cities are the first and second most significant indicators of city centrality in HSR networks, compared to the administrative level of cities and average distance to others in airline networks. The higher elasticities of GDP per capita and population to the HSR centrality index suggested that mode is concerned mainly with connections to cities with higher socio-economic performance. In contrast the centrality index for airline transportation is more sensitive to the average distance to other cities as, airline travel becomes a more suitable alternative for middle- and long-haul journeys. Furthermore, the positive 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 it is that passengers will travel either to/from other cities. However, city centrality is more sensitive to the administrative influence for airline than HSR networks, probably because airlines are more suitable for non-recurrent travel for the purpose of public service obligations while many governmental objectives are administered on a national scale. Therefore, compared to HSR travel, airline travel is targeted more at long haul connections in particular to cities in high administrative levels.

(*footnote continued*)
Liaoning, Hebei, and Shangdong provinces.

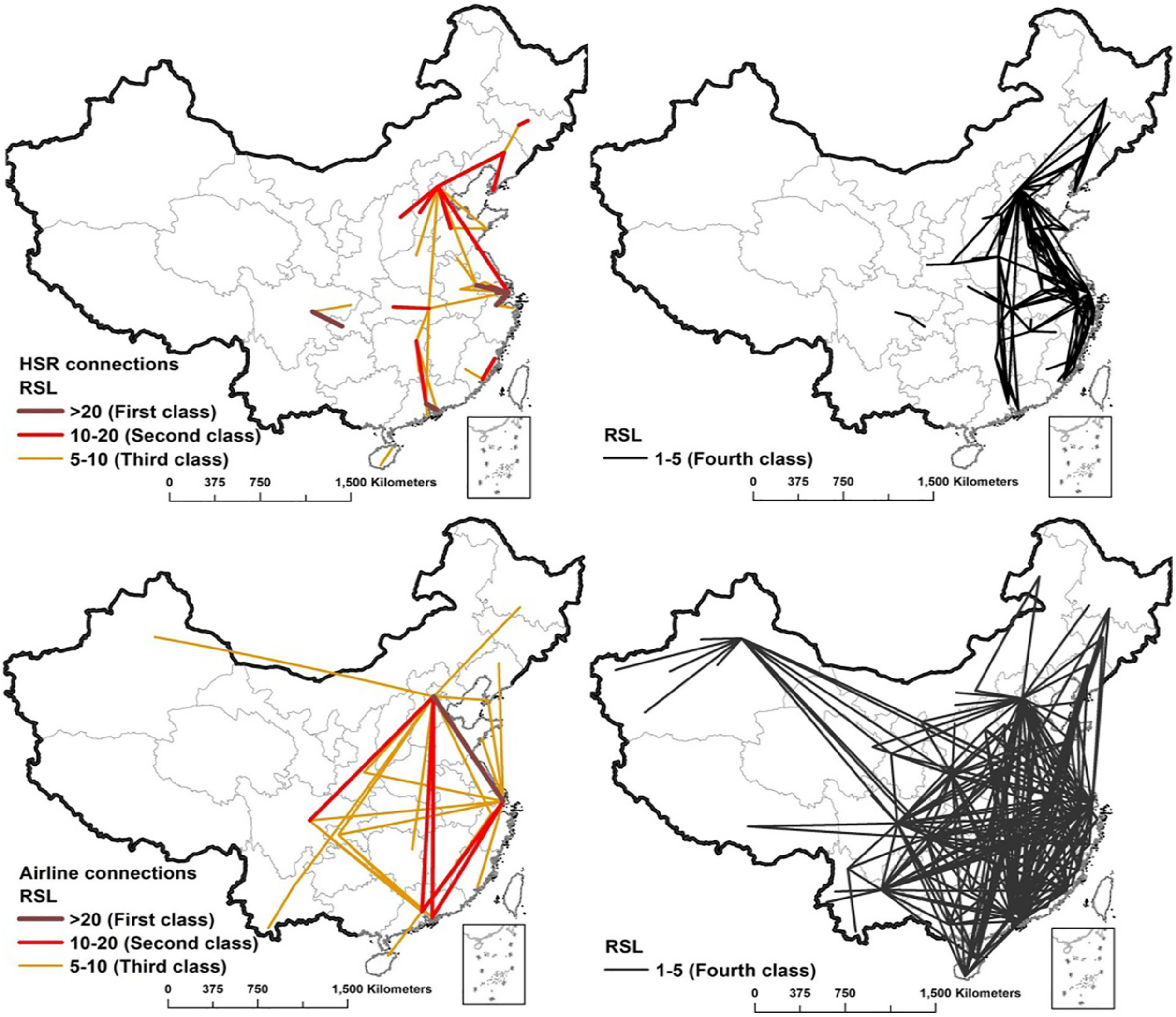

Fig. 5. Rank of link connectivity index for HSR and airlines.

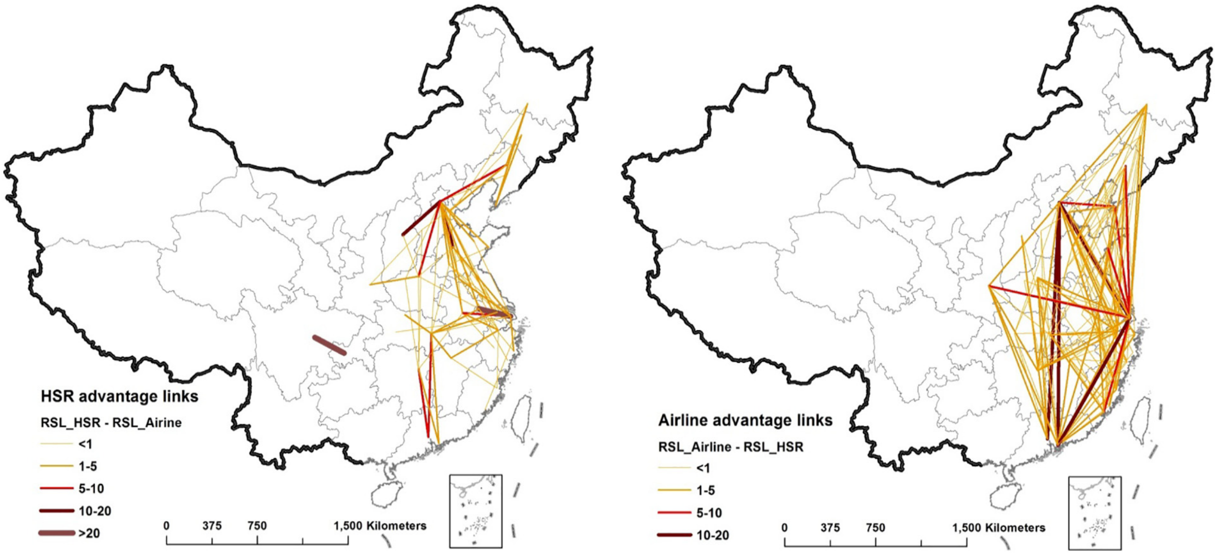

Fig. 6. City links with an advantage on HSR and airline connectivity index. (If one link's RSL value of HSR networks is larger than that of airline networks, it is considered an HSR advantage link or otherwise an airline advantage link.)

Table 4
Multiple regression on city centrality index.

	DIT_HSR[a]	DIT_Airline[a]
	Standardized coefficients	Standardized coefficients
GDP per capita[a]	0.576***	0.184***
Average distance[a]	0.0221	0.299***
Population[a]	0.414***	0.141***
Administrative level	0.185**	0.502***
Observations	105	168
Adjusted R-squared	0.689	0.665

** $p < 0.05$.
*** $p < 0.01$.
[a] Ln transformation.

Table 5
Multiple regression on link connectivity index.

	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

*** $p < 0.01$.
[a] Ln transformation.

Distance and summed administrative level are the most significant factors in the link strength of HSR and airline networks, respectively (Table 5). Link connectivity strength has a much higher negative elasticity compared to the distance in HSR than in airline networks. 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. This makes sense, considering that the attractiveness of HSR services decreases when travel time increases (Givoni and Dobruszkes, 2013). Furthermore, the positive sign of summed administrative level reflects that the nodes of city links with a lower administrative level generally have low travel demand in between. However, the summed administrative level is much more elastic to 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. This indicates that public service obligations or any other governmental objective could serve as additional reasons for offering airline services between distant cities, especially regarding the lower investment in airline construction compared to HSR between those distant cities.

4.3. Community clusters of cities

According to the HCA analysis, we visualized the communities of the HSR and airline network, respectively, in Fig. 7. Community networks refer to city nodes gathered into several groups, in which there is a higher density of city-pair connections within groups than among groups. The dendrograms of the HCA of HSR and airline networks, which are presented in Appendix A, reflect the extent to which city nodes are bonded within each community. A shorter bracket and a lower position in the dendrogram trees indicate a stronger relationship between a pair of cities in the subgroup.

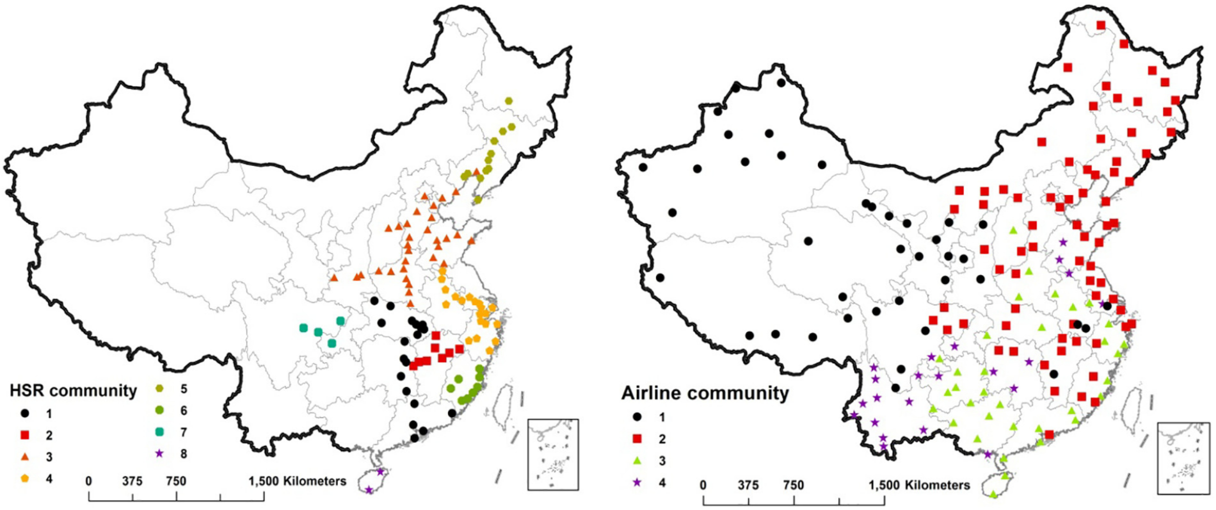

Fig. 7. The spatial distribution of communities.

In the HSR network, with a modularity value 0.58, and there exist eight subgroups with the typical eastern focus which is characteristic of many economic geography distributions in China, as shown in Fig. 7. This confirms that with high speed rail travel geographical proximity matters most in intercity relationships. For instance, in the YRD region (community 4), Shanghai serves as the core and forms the strongest bonds with Hangzhou along the Jinghu and Shanghai-Hangzhou HSR routes. In the northeast with Liaoning, Jilin, and Heilongjiang provinces (community 5), Jilin-Changchun and Dalian-Shenyang form strong bonds along the Jingha HSR routes covering the northeast regions. Furthermore, in Jiangxi (community 2) and Fujian provinces (community 6), there are strong agglomeration effects within each province, where Nanchang-Jiujiang and Fuzhou-Xiamen form the strongest bond, and other peripheral prefecture-level cities are connected by parts of the Hukun HSR route and the southeast coastal HSR route within each province. Along the Wuhan-Guangzhou route connecting the middle and southeast (community 1), cities are also clustered. Furthermore, two clusters are formed due mainly to the geographical isolation and less-developed HSR network connections: Sanya and Haikou, as mentioned before, are isolated from mainland China (community 8) and form a cluster connected by the Hainan HSR route. Another cluster exists in the southwest (community 7), where Chengdu and Chongqing serve as the cores with limited connections with adjacent cities by parts of the Huhangrong HSR route due to the 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 just four subgroups as shown in the dendrogram. These groups do not represent the geographical clusters as seen with HSR, although an eastern and western group is apparent. For instance, Shanghai and Shenzhen form the strongest bond and start the first subgroup, which grows with the addition of Xiamen and Tianjin. Then loosely connected cities in different parts of China are added to enlarge this original group.

5. Conclusions and discussion

This paper contributes to the current research as it clearly reveals China has two different spatial structures of urban systems associated with its two high-speed transportation networks (HSR and airlines). To the best of our knowledge, this paper is the first study to use actual O/D passenger flow data and compare the resulting configuration of the urban systems in these two high-speed transportation networks. These urban systems are likely to reflect the mobility of upper social occupational groups, given the social filter that shapes the use of fast, long-distance transportation modes.

The different spatial structures are well illustrated in the fact that HSR-dominant cities are centralized mainly in the middle and eastern parts of China, whereas airline-dominant cities are evenly distributed over the whole country. This difference can be partly explained by Chinese physical geography; many cities are located far away from each other in the sparsely populated mountain areas of the west region that cannot be easily reached by HSR transportation, in contrast to the cities located in the densely populated plains of the east region. The difference can be further explained by the high sensitivity of city centrality HSR networks to socio-economic performance, in contrast to a higher sensitivity to administrative level of cities and average distance to other cities in airline networks. This is largely a consequence of the relatively expensive investment needed in HSR networks, which are more economically and socially justifiable in high-density passenger volume areas. In other words, HSR networks are less suitable for long-distance travel on a national scale and less viable for low-density passenger volume corridors than airline networks, even though central governments can decide differently for political reasons (de Rus and Nombela, 2007; Dobruszkes et al., 2017). Typically, in this case, more remote but higher administrative-level cities in the low density west part of China in 2013 were usually served by airlines, which is a more cost-effective investment than HSR.

Those differences can be seen in the strong links in the regional connections between the middle and eastern regions facilitated by HSR travel, while for airline travel they are found in connections between the western and eastern regions, consolidating a typical “flyover” effect in China as mentioned by Jin et al. (2004).

The differences were also obvious in community network structures. Cities with dense populations and developed economies tend to cluster in specific regions along trunk HSR lines compared to airline networks which lacked such an obvious pattern. Therefore, it is worth noting that agglomeration economies of urban systems could be facilitated by HSR networks, whereas airline networks contribute relatively to 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.

These findings have some useful implications for the planning of HSR and airline networks in China. The regional focus of the HSR means that it can contribute to the integration of regional urban systems as major cities located in proximity to each other can begin to benefit from agglomeration economies. In the western region this research suggests the potential for air-HSR integrated hub cities, rather than rely on the national HSR network alone. Chongqing, Kunming, Chengdu and Xi'an could play key roles here.

Moreover, this paper illuminates several research perspectives. First, because long-distance transportation networks evolve over time and shape demand to some extent, it will be of interest to replicate our analyses for several years. Indeed, the total HSR length is planned to 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). Current plans call for much of that extension to be located in the western part of China, which could be part of China's link to a Euro-Asia urban systems by the Belt and Road Initiatives. 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 the HSR network additions and greater liberalization in the airline networks have been fully constructed will provide an interesting insight into China's updated urban systems, especially in view of the fact that new HSR developments in western China could. In addition, it would also be interesting to focus more specifically on the shorter-distance market and to investigate whether HSR is used for commuting, in line with travel times and fares. More generally, the impact of fares on flows observed should also be investigated, provided appropriate ex-post data would be available. Finally, since HSR and airline networks are used mostly by upper social-occupational groups (Liu and Kesteloot, 2015; Delaplace and Dobruszkes, 2016), it is of interest to expand our work with intercity travel comprising traditional rail services and road.

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Appendix A

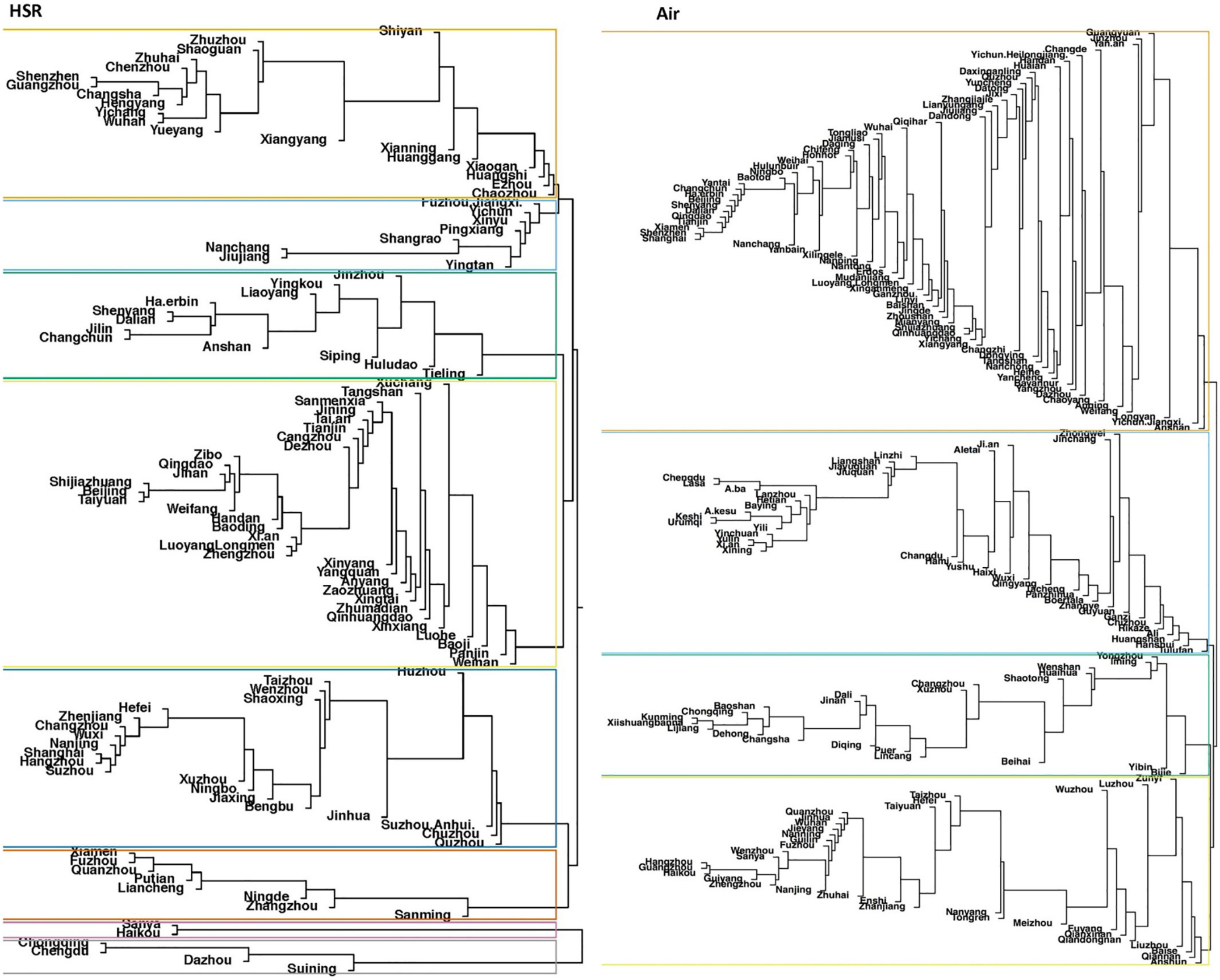

Fig. A1. Dendrogram trees for the HSR and airline networks.

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