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Understanding accessibility changes from the development of a high-speed rail network in the Yangtze River Delta, China: Train speed increases and rail distance deductions

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Abstract: The rapid development of the high-speed rail (HSR) network in China has compressed intercity rail travel times. However, what is contentious is whether the expansion of HSR network has created a landscape of uneven accessibility, i.e. producing winners and losers regarding cities' changing ability to access to the others. This paper uses the Yangtze River Delta (YRD) – one of the most populous and developed mega-regions with the high dense HSR network in China – as a case study to examine accessibility restructuring and major geographical features of winners and losers through a longitudinal comparison before and after the development of the HSR network. Analytical results show that the introduction of the HSR service network has exacerbated the uneven pattern of network accessibility formed by the conventional rail (CR) network. Aside from increased train speeds, intercity travel makes time savings thanks to significant rail distance deductions in the change from CR to HSR services because HSR needs a straighter trajectory, which is usually ignored in the literature. 'Winner' cities are either privileged substantially by a much higher quality of HSR service or a much shorter network rail distance. HSR cities can also lose out due to a large increase in network rail distance and a low quality of HSR service. Except for a few CR cities which neighbor HSR stations, thus winning an above average change, most CR cities are disadvantaged as a result of HSR network development. This paper extends the speed-dominated understanding of accessibility change from the network perspective of HSR services.

Keywords: high-speed rail; conventional rail; accessibility improvement; train services; HSR cities; Yangtze River Delta

1 Introduction

The world's high-speed railway (HSR) network has been in a continuous process of growth since the first HSR line was invented in Japan in 1964 (Campos and de Rus 2009). Particularly following the accelerated economic globalization process of the late twentieth century, we have seen a construction boom of HSR in Europe, with countries such as France, Spain, Germany, and Italy putting massive investment into the expansion of HSR network (Vickerman 1997; Yin et al. 2015). The HSR network

are playing an important role in facilitating the movement of people, goods, and information and thus accelerating the process of regional integration (Garmendia et al. 2012; Cheng et al. 2015; Geng et al. 2015; Huang et al. 2017).

By significantly shortening travel time and providing a high-quality service, HSR trains emerge as the most competitive transport mode for distances of 200-800 km (Givoni 2006). It is well acknowledged that HSR network development will change the pattern of intercity accessibility, leading to a compression of time and space (Ureña et al. 2009; Gutiérrez 2001). However, accessibility improvement resulting from HSR network development is not spatially equal for all cities, and an enlarged disparity of spatial accessibility has been noticed at the regional scale (Jiao et al. 2014; Givoni 2006). Obviously, HSR cities would directly benefit from reducing travel time to other cities and functioning as an interchange node for cities nearby and outside the HSR network (Monzón et al. 2013).

Two main research methods are widely used to evaluate the changing pattern of intercity accessibility brought about by HSR network development (Gutiérrez 2001; Martínez and Givoni 2012). By using GIS network analysis, the first employs different rail networks and their respectively assumed travel speeds to calculate the accessibility surface from different city-nodes over a certain period (Albacete et al. 2017; Monzón et al. 2013). A gravity-based method (based on population size or economic output) is also developed to calculate the weighted average travel time, considering traffic demand (Gutiérrez 2001). The second approach sits much closer to real travel time as it uses the online map-searching service of timetables of different travel modes (Wang et al. 2013; Zhang et al. 2016; Martínez and Givoni 2012). Some studies also calculate intercity accessibility by using a hybrid approach to combine the two methods above (Wang et al. 2013; Shaw et al. 2014).

Previous studies advance scholarly understanding of HSR as an important driver for increasing intercity accessibility. However, some concerns are also raised. The first is that the spatial coverage and frequency of HSR trains have usually been ignored but remain critical components of rail travel (Wang et al. 2013). Particularly for the HSR network, in order to maintain a high speed, many HSR trains travel non-stop through small cities, something which cannot always be reflected in terms of accessibility surface modeling. Secondly, accessibility modeling initially assumes there are no gateways, which is not realistic as rail networks are hierarchical in nature (Wang et al. 2012). In reality, hub-and-spoke networks are widely employed in the overall transport system of spatial organization (O'Kelly 1998). Cities in the hierarchical rail network vary across external transport demand (as to the important function of gateway cities in railway networks, see Yang et al., 2018). Gateway cities are concentrator nodes where traffic is concentrated and evacuated (Liu and Xu 2017). Thirdly, previous studies tend to overlook the role of the conventional rail (CR) network and its relation to the HSR network (Martínez and Givoni 2012; Banister and Givoni 2013). In China's case in particular, even though HSR trains dominate and will

increase their share in the passenger transport system, the absolute number of CR trains is still increasing (Shaw et al. 2014). By offering a much cheaper service and more stations, CR trains would complement HSR trains in certain areas. Further, the change in rail distance from the CR to the HSR network is usually ignored. Many countries have developed a dedicated HSR line that is not compatible with CR trains (Campos and de Rus 2009). The HSR line might be parallel to the old CR line generally, but most often it needs to adopt a straighter trajectory for technical reasons (Ollivier et al. 2014). This means that when measuring travel time savings from a CR to HSR network, the change of relevant rail distance should also be considered in order to avoid overestimating the advantage of HSR services. Subsequently, evaluating regional accessibility improvement from HSR network development should comprehensively consider the spatial coverage of train services, as well as the different types of train service traveling in the different rail networks.

Although a late-starter, China has a great interest in developing a dense HSR network as the country has a vast territory and high population density, particularly in its eastern regions. Since the first HSR service was started in 2003, China has established the largest HSR network in the world, much of which has been newly constructed in the past decade. From 2008 to 2014, passengers using HSR increased by an annual growth rate of 39% (Ollivier et al. 2014). According to China's ambitious *Mid-to-long Term Railway Development Plan* (first published in 2004, and further revised in 2008 and 2016), all cities with a population larger than 500,000 will eventually be connected by an HSR network, with a total line length of 38,000 km estimated by 2025.

Against this backdrop, this paper is designed to understand changing intercity and network accessibility from HSR network development in regional China. Rather than re-assessing the impacts of HSR on accessibility in China, which has been widely discussed in existing literature, this paper takes account of the major concerns mentioned before in framing this study. Taking the Yangtze River Delta (YRD) – one of the most populous and developed mega-regions with high dense HSR network in China – as a case study, this paper aims to answer the following two interrelated questions: (1) what are the major geographical features of winner and loser cities at the county levels or above from the development of an HSR service network? and (2) how have train speed increases and rail distance deductions contributed to the different performance of corresponding cities? The next section is an introduction of the research methodology. The third and fourth sections are empirical analysis of changing accessibility from the CR to HSR services in the YRD. Some conclusions and discussion are drawn in the last section.

2 Research methodology

2.1 Study area

The YRD is one of the most developed mega-regions, located in eastern China (Figure 1). This region includes 4 province-level units with cities at 42 prefecture-level or above. In 2015, it had a population of 220.7 million, with GDP US\$ of 2,570.99 billion. The rail network in the YRD are relatively developed and ranked the second largest in the 18 local branches of the National Railway Administration in China. In April 2008, the first HSR line (from Nanjing to Hefei) was set in operation, while 16 HSR lines were operating in Oct 2016. The total length of HSR lines was 3,771 km in October 2016, extending to 33 prefecture-level or above YRD cities. Meanwhile, in 2016, the CR passenger network extended to a total length of 5,394 km, covering 37 prefecture-level or above cities. Compared to the fast development of HSR lines, CR lines have only increased by 630 km over the past decade, tending to optimize sub-regional connections on the basis of the well-developed CR network. Consequently, the YRD provides a revealing case for studying the development of HSR network, allowing for a critical assessment of their impact on intercity accessibility, along with the CR network.

In the Chinese context, a prefecture would administrate a central prefectural city with several small cities or rural counties, the so-called ‘city administrating county system’ (for more details, see Li and Wu (2012). The county is the lowest administrative level for rail transport planning in China and thus the basic spatial unit for this study. In general, higher administrative levels are associated with greater numbers of rail stations and frequent train services (Zhu et al. 2015). Previous studies have used the prefecture to evaluate rail accessibility, and this may result in an oversight regarding the rail accessibility inequality within the prefecture because the administrated counties may not all operate a rail service.

Figure 1 Location of the study area

2.2 Research methods

Train speed and rail distance are two major factors that determine intercity rail travel time. In practice, the travel time cannot be calculated simply through a division formula, because the speed is offset by stops along the journey (Qin 2017). Each stop would add a journey time of 5-10 minutes to accommodate the deceleration and acceleration of train services and to load and unload passengers (Givoni and Banister 2012). Thus, the calculated speed from the timetable of train services could be much lower than the operation speed.

A widely-used location-based measurement (Gutiérrez 2001; Jiao et al. 2014) is employed to calculate rail accessibility in this study. Indicators of intercity and network accessibility are captured by the real travel time based on the official train timetables. We use average travel time for all CR and HSR train services between any two cities as the basic indicators respectively. The average travel time is used because different qualities of train services are offered between cities (Wang et al. 2013). The average travel time provides a fair comparison between different routes.

$$\bar{t}_{ij} = \sum t_{ij} / n \quad (1)$$

Where: t_{ij} is the travel time of train service between any city i and city j , and n is the daily frequency of direct train service of CR or HSR services between the two cities. For cities such as Shanghai, Nanjing, and Hangzhou, which have more than one HSR or CR station, we used the main station in the intercity analysis and added their travel times to other stations.

We calculated the indicators of a city's minimal total travel time to all destination cities through network analysis in the ArcGIS environment. Similar to the studies of Shaw et al. (2014) and Moyano et al. (2018), the destination cities for calculating network accessibility are regional political and economic centers. Specifically, they are 4 provincial capitals and 24 prefectural cities in the YRD. We added a 30-minute waiting time penalty if a transfer to a nearest third city was needed.

$$NT_i = \min \sum_k \bar{t}_{ik} \quad (2)$$

Where: k represents one of the 28 regional centers, NT_i is the minimal total travel time of city i to all regional centers. The equation allows lower value of NT, higher network accessibility in a given city. Subsequently, two patterns of network accessibility (the 2007 CR network and 2016 HSR network supplemented by the 2016 CR network, abbreviated as '2007 CR' and '2016 HSR' respectively hereafter) are established to explore the changes over a decade of HSR development in the YRD.

We used both absolute change and relative change values to capture the improvement of intercity and network accessibility. Absolute travel time saving is an intuitive measurement that relates to a subjective perception of distance, while relative travel time saving enables a fairer comparison to eliminate the size effect (Waterson and Box 2010). The paper also employs the Gini coefficient to explore regional disparities of network accessibility.

It is worth mentioning that some cities opened or withdrew train services during the study period, which makes it difficult to analyze accessibility changes in individual cities. To deal with the problem of inconsistent lists of cities having train services in the two periods, we only compared individual changes for the 89 cities (31 were CR and 58 were HSR cities) at the county-level or above that maintained consistent train service during the two time intervalsⁱ, although we included all rail cities (99 in 2007 and 122 in 2016) in our investigation of the general pattern of network accessibility.

2.3 Data collection

Two official train timetables were collected to explore the changes of intercity accessibility. The dates are 18 April 2007 (pre-HSR era) and 24 October 2016 (HSR era with 16 lines)ⁱⁱ. The first timetable comes right after the sixth round of the 'speed-up campaign' by the Chinese railway system. After that, CR trains stabilized their operation speeds, which is a good benchmark for assessing the travel time savings resulting from the introduction of the HSR network. The second timeslot appears right after the new round of train timetable restructuring due to the operation of the newly built Zhengzhou-Xuzhou HSR line. In 2016, HSR trains in the YRD were of two types. The first starts with a train letter D, operating at a speed of

200-250 km/h, and the second starts with a train number G, operating at a speed of 250-300 km/h.

In this paper, we aggregate multiple CR and HSR stations in a city as either a main CR or a main HSR station, and exclude train services within the same city. The 2007 timetable includes 591 trains serviced in the YRD with 15,012 intercity connections, while the number increased to 2,070 and 48,375 respectively in 2016. In the 2016 timetable, there were 705 CR trains with 13,930 CR intercity connections and 1,365 HSR trains with 34,445 HSR connections (Figure 2). It shows that the number of trains increased by 250.3% and the intercity train connections increased by 247.3% over the course of a decade. The number of CR trains increased by 20.3%, but CR connections decreased by 7.7%. By taking 65.9% of the number of trains and 71.20% of intercity connections, HSR services became the dominant rail transport mode in the YRD. As reported on the experiences in the EU, CR train services decrease significantly when an HSR network is introduced (Givoni 2006). The decline of intercity CR services will be probably continued in the YRD in the coming future.

Figure 2 Number of train services per day and intercity train connections operating in the YRD

3 Intercity rail travel time savings from CR to HSR services

3.1 Intercity rail travel speeds, distances and times of CR and HSR services

Intercity rail travel time is associated with the travel distance and train speed. Thus we examine rail travel time savings from two perspectives in the YRD: train service upgrading from CR to HSR to increase train speeds and train schedule rearrangement to reduce travel distances.

The calculated average speed of CR trains was 67.9 km/h in 2007, slightly down to 66.9 km/h in 2016. In contrast, the average speed of HSR trains was 153.3 km/h, increased by 125.6% from CR services. However, it was significantly lower than its

operation speed ranging from 200 to 300 km/h. Thus, at the same rail distance, the travel time saving was 55.7% on average from CR to HSR services in the YRD.

In the 2007 CR service network, the average intercity rail travel distance was 412.4 km, but, after a decade of rail services development, the figure reduced significantly to 341.8 km for the HSR service network, and 391 km for the CR service network in 2016. A shorter intercity rail distance was mainly because HSR lines need many more straight lines than CR on the one hand, while on the other, HSR network development had increased overall rail density, which meant more cities were connected by train services.

There were 1,289 city-pairs with consistent train services over the two interval-years. The number accounts for 73.5% and 47.6% of total city-pairs with train services in 2007 and 2016, respectively; 696 were upgraded to HSR services, and 593 persisted in CR services. Figure 3 presents a scatter plot of city-pairs with different travel times in the two years. It provides an immediate picture of two groups of CR services and HSR services. In general, there were also statistically significant correlations ($r=0.7638$, $p<0.01$, $n=1289$) between travel times for city-pairs in 2007 and 2016. The HSR service had significantly compressed the intercity travel time in 2016, and its difference from the CR service has increased along the increase of intercity travel time in 2007. In contrast, CR services stabilized the intercity travel time over the past decade, which can be reflected in the slope of its correlation curve in the figure 3. Meanwhile, there were also many upwardly and downwardly mobile city-pairs. This was mainly because city-pairs have changed the rail distances and qualities of train services from HSR development and CR schedule rearrangement.

Figure 3 Intercity travel times in 2007 CR services network versus in 2016 HSR services network

3.2 Intercity travel time saving from CR to HSR services

Figure 4 presents city-pairs with the top 50 largest absolute and relative travel time savings from HSR services development. It is clear that most of the city-pairs at the highest absolute travel time savings were between HSR cities located in periphery areas, such as rail connections between Shanghai and cities located in southern Zhejiang, northern Jiangsu and western Anhui. The accelerated train speeds from the CR to HSR networks show that the longer the distance between city-pairs, the greater the travel time savings. However, the straight-line distance only very partially informs our understanding of travel time savings in the YRD. By changing CR to HSR services, the actual rail track distances were also changed significantly, which affected train travel times. For example, the city-pair of Shangyu-Liu'an had the highest deduction of intercity rail distance by 362 km, which saved 2.5 hours by using HSR based on the average speed, followed by Qingtian-Chuzhou with deductions of 324 km rail distance and 2.2 hours.

In contrast, lower travel time savings occurs in two types of city-pair. The first is where the city-pair has a short rail distance, as HSR trains cannot utilize advantageous high speeds because it takes time to speed up and slow down. City-pairs such as Huzhou-Changxing (20 km), Yangzhou-Jiangdu (25 km), and Hai'an-Rugao (20 km) belong to this type. The second is where the city-pair has a significant rail distance increase which cannot be counteracted by a train speed increase from CR to HSR services. Hangzhou-Fanchang (+252 km), Hangzhou-Wuhu (+244 km), and Yiwu-Wuhu (+213 km) belong to this type of city-pair. Even in the CR network, there were deductions in intercity rail distance because of train schedule rearrangements, such as for the city-pairs of Shangyu-Liu'an (-362 km), Hangzhou-Liu'an (-281 km), Huainan-Zhuji (-198 km), while some intercity CR rail distances were slightly increased for city-pairs such as Chaohu-Huaipei (+73 km) and Nantong-Xuzhou (+43 km).

As absolute travel time saving is associated with rail distance. We used relative travel time savings to eliminate the size effect. Figure 4 shows that only a few city-pairs with the largest absolute travel time savings fall into the zone of the top 50 city-pairs with the largest relative travel time savings. In contrast, many city-pairs with a lower relative travel time saving are also those with lower absolute travel time savings, such as city-pairs along the Nanjing-Nantong HSR (an upgraded line from CR). City-pairs between cities in southern and central Anhui have gained the largest relative time saving because the Hefei-Huangshan HSR cuts across the trajectory of the CR line. City-pairs between cities in the Hangzhou metropolitan area and Nanjing metropolitan area and its northern cities along the Beijing-Shanghai HSR also got the highest relative travel time savings because the operation of Nanjing-Hangzhou HSR in 2013 fills a vacancy in the train services triangle for the three most important YRD central cities of Shanghai, Nanjing and Hangzhou. Previously, train services between Nanjing and Hangzhou needed to make a detour through Shanghai.

Figure 4 Top 50 and bottom 50 city-pairs of absolute and relative travel time savings from CR to HSR services between 2007 and 2016

Table 1 Characteristics of city-pairs with top 10 and bottom 10 absolute travel times savings from CR to HSR services between 2007 and 2016

		Average travel time (hour)		Average rail distance (km)		Accessibility increase (2007-2016)			
		CR 2007	HSR 2016	CR 2007	HSR 2016	Absolute change (hour)	Relative change (%)	Distance deduction (km)	Speed increase (km/h)
Top 10 absolute time change	Wenzhou-Huainan	19.58	7.21	1223	1036	12.37	63.17	187	81.19
	Wenzhou-Xuzhou	17.70	6.05	1250	1019	11.64	65.79	231	97.69
	Qingtian-Xuzhou	16.44	5.12	1193	884	11.32	68.84	309	100.00
	Qingtian-Bangbu	15.01	4.35	1046	728	10.66	71.02	318	97.67
	Wenzhou-Bangbu	16.24	5.66	1103	891	10.58	65.13	212	89.44
	Shangyu-Liu'an	14.87	4.30	990	628	10.57	71.10	362	79.60
	Lishui-Xuzhou	15.26	4.91	1114	834	10.35	67.80	280	96.76
	Lishui-Suzhou	14.42	4.11	1051	758	10.30	71.47	293	111.41
	Wenzhou-Chuzhou	14.96	4.94	993	758	10.01	66.95	235	86.96
	Qingtian-Chuzhou	13.87	3.88	936	612	9.98	72.00	324	90.10
Bottom 10 absolute time change	Jiangdu-Taizhou	0.43	0.30	39	39	0.13	0.31	0	40.00
	Danyang-Zhenjiang	0.34	0.21	28	27	0.13	0.39	0	47.59
	Huzhou-Changxing	0.26	0.15	19	20	0.11	0.42	0	57.97
	Rugao-Nantong	0.49	0.41	45	45	0.08	0.16	0	17.69
	Jiaxing-Jiashan	0.22	0.14	18	17	0.08	0.34	1	35.76

Jiaxing-Haining	0.34	0.27	28	49	0.07	0.20	-21	98.93
Haian-Rugao	0.25	0.20	20	20	0.05	0.20	0	20.38
Dangshan-Xiaoxian	0.35	0.33	34	67	0.02	0.05	-33	103.86
Yangzhou-Jiangdu	0.28	0.30	25	25	-0.02	-0.06	0	-4.90
Hangzhou-Wuhu	4.0	4.3	315	559	-0.34	-0.08	-244	50.33

4 Changes in network accessibility from CR to HSR services in the YRD

4.1 Patterns of network accessibility

To clearly mapping the global patterns of network accessibility, we project cities' NT values to their administrative regions. Figure 5 shows the two patterns of network accessibility for rail cities in 2007 and 2016. The NT values, which are indicated by colour bar, are grouped by the natural break method in this figure. The obvious observation is that there manifested a core-periphery *backbone* structure of network accessibility in both years. However, the development of the HSR service network has weakened the previous core-periphery structure. In general, lower NT values were mainly clustered in a prominent corridor comprised of the provincial capitals of Hefei, Nanjing, Shanghai, and Hangzhou. This is in line with the economic landscape of the YRD: the quadrilateral corridor is the most important urbanized area with developed industries in this region, as well as the core area for the central government to promote regional integration. Furthermore, to *globally* quantify the regional disparity of network accessibility in the YRD, we measure its Gini index in the two periods. The result shows there is an increasing trend, with the Gini index rising from 0.13 to 0.18.

More specifically, in 2007, cities with the lowest NT value were mainly located in the greater Nanjing metropolitan area, the geographic center of the YRD. Some geographically peripheral cities such as Xuzhou, Fuyang, and Jinhua, although located at the hub of the rail network, had relatively higher NT values. In 2016, the number of cities with the lowest NT values has expanded towards the eastern and western areas. Some enclaves with relatively lower NT values, such as Xuzhou, Huaibei, and Suzhou-AH, also emerged in the northern periphery area. Compared with the CR service network, the HSR service network has compressed intercity travel time and resulted in overall NT deductions. HSR service has much strong power in overcoming the location disadvantages of some geographically peripheral cities, such as Shanghai, Xuzhou, and Ningbo. Although some peripheral cities such as Wenzhou and Jinhua in the southern YRD have developed HSR services, the NT values for these cities were still relatively high because their rail distances to other cities in the YRD are very large.

Among 89 cities with consistent train services, the pattern of NT in 2016 was significantly correlated with that in 2007 ($r=0.785$, $p<0.01$), but there is at least a 35% difference between the two patterns. The result echoes the mapping analysis that HSR

services have affected the NT values of core-periphery structure in 2007. Obviously, the degree of improvement varied across HSR and CR cities (Figure 6). There were also many upwardly and downwardly mobile cities. The variation is much higher for CR cities, evidenced by a lower adjusted R^2 . This is mainly because CR cities vary across each other's rail distances to the nearest HSR station. The mobile HSR cities suggest that there are varied train speeds for different routes and rail distance changes between the two years.

Figure 5 Patterns of network accessibility in the YRD in 2007 and 2016

Figure 6 Correlations of network accessibility between 2007 and 2016 for CR and HSR cities

4.2 Ranking changes in network accessibility

The most obvious place to start to examine pattern change is to look at the ranking shifts. Examining ranking changes in network accessibility is an easy way to find which cities and regions have benefited more than others from HSR network development. Figure 7 presents the ranking changes for cities with consistent train services in 2007 and 2016. Warm colors mean a ranking increase, while cold colors suggest ranking declines.

Except for the 6 cities of Shanghai, Nanjing, Jiaxing, Kunshan, Changfeng, and Jixi, most of the 89 cities had a ranking change. Actually, the 6 stable cities are all HSR cities and their network accessibility featured above the average in 2007. The change is most obviously shown by the entry of Bangbu, Dingyuan, and Changxing, and pulls Xuancheng, Chaohu, and Wuhu into the top 10. In addition, Anqing, Xuzhou, and Lishui had major network accessibility gains greater than +25. Cities with the most significant decline are Ningguo (from 28 to 66), Xuancheng (from 8 to 43), Guangde (12 to 42), and Fuyang (from 52 to 75), all of which are close to the CR network hubs but excluded from HSR development. Most CR cities have lost ranking gains, while some CR cities such as Pizhou, Shuxiang, Donghai, and Suyang in the peripheral areas had a ranking increase mainly because their initial ranks were very much lower, and they are close to a neighboring HSR station. In contrast, most HSR cities had ranking gains except stable cities; the cities of Changzhou (-1), Suzhou (-2), Wuhu (-16) and Chaohu (-14), which located in the geographic center and had very high initial ranks in 2007; and other cities located along the upgraded line of Nanjing-Nantong HSR had greater ranking declines because this carries a lower speed of HSR services.

Generally, the development of the HSR network has prioritized cities at the prefectural level and above because their aggregated ranking changes were 63, in contrast to the rest of the cities at the county level. The three provinces of Jiangsu, Zhejiang, and Anhui also had unbalanced gains in ranking changes. Among 25 rail cities in Jiangsu, except for Xuzhou (+24), ranking gains for winner cities were relatively low ($<+6$) but rank losses for cities such as Nantong (-14), Yancheng (-13), and Jiangdu (-13) were relatively higher, which resulted in a negative aggregated ranking change of 76. In Anhui province, 39 rail cities also had an aggregated ranking deduction, but with much a higher figure of 177. In contrast, 24 rail cities in Zhejiang province had a positive aggregated ranking change of 253. Except for Lanxi (-6), Jiashan (-1), Haining (-1) with slight ranking decreases, most of the cities in Zhejiang province had ranking gains. Among the three provinces, Anhui had the largest variation of ranking changes, evidenced by the measurement of standard deviations of Anhui (15.79), Jiangsu (8.39) and Zhejiang (8.77). The result indicates that HSR network development has had the most significant effect on the differentiation of cities in Anhui province.

Comparing to Jiangsu and Zhejiang provinces, Anhui has better developed CR

network because the province is relatively centrally located in China and several national backbones CR lines. This is why, although located in the periphery area of the YRD, many cities had relatively higher network accessibility values in 2007. However, HSR network development in Anhui province is centred by the provincial capital, Hefei and only part of cities have accessed to the HSR network. Thus, HSR development produced the enlarged change of cities' network accessibility from 2007 to 2016. For instance, Fuyang in Anhui province was one of the major national CR hubs and has not been accessed by HSR services, while the development of HSR network has replaced its position for Hefei to be the national rail hub.

Figure 7 Ranking changes in network accessibility between 2007 and 2016

4.3 Determinants of changing network accessibility and winner and loser cities

The development of the HSR service network has compressed cities' network accessibility dramatically in the YRD. Of 89 cities over the past decade, the absolute and relative changes in NT were 104.89 hours and 51.88% on average respectively. Obviously, the NT decrease varies across CR and HSR cities. The average absolute and relative changes for CR cities (95.21 hours and 42.01%) were significantly lower than those of HSR cities (110.05 hours and 57.17%). Consequently, the development of HSR services enlarged the gap between HSR and CR cities.

Cities in peripheral areas benefited more from an absolute NT deduction because of their higher NT values. For example, HSR cities such as Wenzhou, Qingtian, and

Lishui in the southern Zhejiang province experienced an absolute NT deduction of more than 165 hours. The CR cities of Qimen, Pizhou, and Xinyi on the radius of the HSR network also experienced an absolute NT deduction of more than 120 hours. However, a larger absolute change does not guarantee a higher relative change for a given city. Only half of the top 10 cities of relative change drop into the top 10 cities of absolute change. This is mainly because relative change is more associated with the quality of HSR services.

In order to find which cities have gained more than others in network accessibility, we further plotted the 58 HSR cities and 31 CR cities into four quadrants using the mean values of absolute and relative NT changes between 2007 and 2016 (Figure 8).

The upper-right quadrant indicates that cities have both absolute and relative changes in NT above the average. Except for Pizhou (neighboring Xuzhou HSR station), they are all HSR cities. It shows that most cities had significant rail distance deductions. For example, Wenzhou, Qingtian Jiangshan, Lishui, and Quzhou are the top 5 cities having a rail distance deduction. The reason for the others located in this quadrant is because, despite a small rail distance deduction, they enjoy a much higher quality of HSR services. Xuzhou, Xiaoxian, Suzhou-AH, and Dangshan had train speed increases of more than 97 km/h, where the average was 56.43 km/h.

Cities in the upper-left group are associated with above-average relative change but below-average absolute change in NT. Compared to the first group, all cities in this group enjoy a relative higher quality of HSR services, but have moderate deductions in rail distance. Besides, more of cities in this group had relatively higher network accessibility in the CR network in 2007. For example, all four provincial capitals in the YRD are located in this group.

In general, the two lower quadrants are dominated by CR cities, except for a few HSR cities that had comparatively smaller rail distance deductions and lower quality HSR services. Cities in the lower-right quadrant are the winners in the group of CR cities. The reason is because they are located in the periphery areas and neighboring HSR stations. In contrast, cities in the lower-left quadrant are losers in the network accessibility improvement from HSR network development. Some cities like Xuancheng, Ningguo, and Guangde in Anhui province had relatively higher network accessibility in the CR network but were disadvantaged by HSR network development. Others, such as Huaiying, Yancheng, and Funing in Jiangsu province, were poor in CR network accessibility and marginalized by HSR development.

Figure 8 Absolute versus relative change of NT values between 2007 and 2016

5 Conclusion and discussion

Along with the rapid development of China's HSR network, mushrooming papers are reporting on the new disparities, corridor effects and core-periphery structure of intercity accessibility patterns (Wang et al. 2009; Shaw et al. 2014; Jiao et al. 2014). This article does not aim to repetitively report the differences between hub cities and other cities regarding changing accessibility; rather, it assumes their difference as a precondition of accessibility analysis in the rail network which has been formed during the long period of transport development. Many studies have emphasized increased train speeds from the CR to HSR network, but have not examined corresponding rail distance changes that also contribute to travel time savings. Through a consistent longitudinal analysis before and after HSR network development in the YRD, this article examines the changing patterns of intercity and network accessibility, and how they are affected by train speed increases and rail distance deductions.

The results are mainly twofold. First, the average speed of HSR service was 153.3 km/h. Although it has increased by 125.6% from the CR service, it was significantly lower than the operational speed ranging from 200 to 300 km/h. HSR network development has reduced average intercity rail distance from 412.4 km in 2007 to 341.8 km in 2016. As expected, city-pairs between periphery HSR cities having long-range train distances, have gained the highest absolute travel time saving, while city-pairs such as Yangzhou-Jiangdu, Jiaxing-Haining, and Hai'an-Rugao with a rail distance under 50 km have the lowest relative intercity travel time saving. But city-pairs with significant rail distance increases changing from CR to HSR services also resulted in a lower relative intercity travel time saving. Therefore, without incorporating corresponding rail distance change, any practices of examining intercity

travel time savings from the CR to HSR network maybe overestimated.

Secondly, the development of the HSR service network in the YRD has weakened the previous core-periphery structure but enhanced regional disparity of network accessibility at the regional scale. Among the three provinces, cities in Zhejiang have been most privileged and gained an aggregated upward ranking change in NT followed by downward ranking changes in Jiangsu and Anhui. At the city level, both the train speed increase and rail distance deduction have contributed significantly to absolute and relative network accessibility change. Therefore, cities outperforming others to become winners depend on both a higher quality of HSR services and a shorter rail distance. In light of this, some HSR cities also lose out due to a significant increase in rail distance. Except for a few CR cities privileged by neighboring an HSR station to win above the average, most of them are losers in network accessibility improvement.

Efficiency and equality are two dimensions have been hotly contested in regional accessibility (Zhao and Lü 2009; Monzón et al. 2013). Generally, compared to the era of CR rail service, the development of HSR network has significantly improved intercity and network accessibility in the YRD. The results show that the development of the HSR network has been focused more on spatial efficiency in the YRD. This strategy is understandable because HSR projects are extremely expensive and their development is connected with the consideration of investment returns and wider economic impacts. However, what is contentious and a focus of this paper is whether this major infrastructural network investment has created an uneven landscape, producing winners and losers. Clarifying this will allow relevant policy interventions to be proposed, either for winners to take advantage of transport-induced development, or for losers to mitigate the potential ‘peripheralization of the periphery’. Similarly, this study reflects the different planning principles of CR and HSR networks. The CR network serve to access broader regions and offer equal and basic connectivity to small cities, while the HSR network pursue to offer more direct and speed connections between main nodes (at least at this stage). And this reminds policy-makers that there is a need to frame unified planning principles by giving consideration to both efficiency and equality, with the aim of coordinating the existing HSR and CR networks.

There is a big difference between China and other pioneering HSR countries with respect to the patterns of CR service along with the rapid development of HSR service. Rather than declining as reported by Banister and Givoni (2013), CR trains in the YRD are still growing in total number and playing an important role in rail transport, although the number of intercity services has declined. This is mainly because CR trains offer much cheaper choices and wider spatial coverage than HSR trains in China. This is particularly true for inland areas where income levels and rail service densities are relatively lower. Therefore, it generates a future research question how to improve the equality of regional accessibility by coordinating CR and HSR service

networks.

Although our framework has, again, verified the inter-city and network time-space compression brought from the development of HSR network, the varied time costs of accessing to railway station arisen at the urban level, as HSR stations always locate at fringes of cities. Furthermore, the time costs of inter-station transfers, which often occur in long-distance train trips in China, also increase (Shaw et al. 2014). Apparently, this intra-city travel time offsets the gains in travel time saving brought by HSR (Diao et al. 2017). However, the scale of cities varies significantly in the YRD, which makes the intra-city travel distance less comparable among different cities and city-pairs at the regional scale. This paper simply ignored the intra-city travel, while highlighted the inter-station travel time between cities resulting from HSR network development. However, the increased travel time and distance to HSR stations play an important role in accessibility analysis at the city level, which is identified as an avenue for future research.

Some other issues are also identified for future studies, such as an analysis of the relation between HSR and CR services, along with cities' socio-economic development. In order to capture the multiscale nature of regional accessibility, future studies might consider the national scale in the rail system. Moreover, inner-city accessibility to HSR stations should also be added to the accessibility analysis as some HSR stations are located in periphery areas. The change in rail stations might lead to additional travel time costs. Lastly, studies conducted from the perspective of HSR users are called for, in order to look at who are winners and losers in terms of different social groups.

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ⁱ The data was derived from www.12306.com (accessed 24 October 2016) and 2007 version of train timetable (18 April 2007), China. We built intercity network in the GIS environment based on the timetable of intercity direct train services. All city-pairs that have direct train services in both 2007 and 2016 were selected.

ⁱⁱ The HSR service was also first introduced on 18 April 2007 after the sixth speed-up campaign in China. In the YRD, a few D-titled trains were introduced and operated on the upgraded CR track of Jing-Hu line's Nanjing-Shanghai section. Due to its operating speed less than 200 km/h, most studies regarded the trains as quasi-HSR services. It was not until April 2008 that the first newly built intercity HSR line in the YRD was operated between Nanjing and Hefei. We chose the most recent timetable before the newly built HSR lines to control the variable of operation speeds for CR trains in the pre-HSR era and the HSR era, we chose to overlook the HSR trains on the upgraded CR lines with a few number of train services, and thus treating the 18 April 2007 as the pre-HSR era.