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Impacts of high-speed rail on domestic air transportation in China

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ABSTRACT

This study investigates the impacts of high-speed rail (HSR) on domestic air transportation in China using a new comprehensive modeling framework utilizing both demand and supply perspectives. For the first time the assessment was conducted using an improved panel regression model by taking into account of the detailed opening schedules of various HSR services during the period 2001–2014. The research findings reveal that the deployed HSR services have a significant substitutional effect on domestic air transportation in China, but the effect varies across different HSR routes, travel distance and city type. Specifically, the research found a decrease in domestic passengers of 28.2%, in flights of 24.6% and in seat capacity of 27.9% after the introduction of HSR services. The impacts are found much stronger among those air routes that connect major hub within a distance range of 500 to 800 km. The uneven nature of the impact can be seen in the different experiences of selected cities. For example, air travel declined approximately 45% after commencement of the Wuhan-Guangzhou HSR, whereas it fell by 34% after the opening of the Beijing-Shanghai HSR.

1. Introduction

The domestic intercity transport system experienced a revolutionary transformation in China during the past decade with the development of high-speed rail (HSR) in the early 2000s. Unlike any HSR in the world, the HSR in China now has the largest network consisting of eight east-west-bound and eight north-south-bound HSR passenger dedicated lines (PDL), with a total track length of over 19,000 km. These new high-speed train services generally operate on dedicated track which can allow operating speeds of 250 km/h or even higher. Because of this high transport capacity and travel speed, the intercity travel demand may have been induced considerably. For instance, as illustrated in Fig. 1, the passenger railway demand has experienced a rapid growth from 2003 to 2013. The ridership on travel distances ranging from 101 to 501 km experienced the fastest growth. In terms of passenger-km traveled, distances over a thousand km accounted for the largest share of the total passenger-km traveled, however, it is actually the rail trip ranging from 501 to 1000 km that increased the most. These statistics confirm that passenger rail travel in China has changed fundamentally in the past decade, which may have serious consequences for air transport.

In fact, during the last decade, the operations of several HSR routes have led directly to permanent cancellations of air services. For instance, as indicated by Chen and Haynes (2015), the Air Express service between Chengdu and Chongqing was discontinued in November 2009 after nineteen years of operation following the opening of the intercity HSR serving the same corridor. One month later, the operation of the Wuhan-Guangzhou HSR led to the cancellation of the Hainan Airline's service between those two cities. One year later, the operation of Zhengzhou-Xi'an HSR also led to a cancellation of all air services between the two cities in March 2010. It is likely that the impact upon air transportation services may be felt in more services as additional HSR services are provided.

However, the interaction between HSR and air transportation is not straightforward as various factors, such as the distance between cities, and their market characteristics, can complicate the competition between the two modes. Considering an "ideal" travel time for an intercity trip can range from one to 4 hours (Givoni, 2006), HSR, which normally runs at a speed of over 250 km/h or higher, is considered competitive for trips between 160 and 800 km (Button, 2012), whereas air is preferable for a longer distance. Market characteristics reflect the values that travelers place upon travel cost and time, and also reflect the size of the cities involved in the link. These different attitudes can be felt in different levels of demand for services.

Understanding these relationships in China is complicated by two aspects of the new system. First, since most HSR services in China were opened recently (after 2010), there is a lack of sufficient data to capture the dynamic response of aviation service to the new competition Second, the assessment of the temporal and spatial evolution of the Chinese HSR system is challenging due to the complicated nature of its construction. Since the development of such a gigantic infrastructure system involves a multistage planning, financing and construction, the

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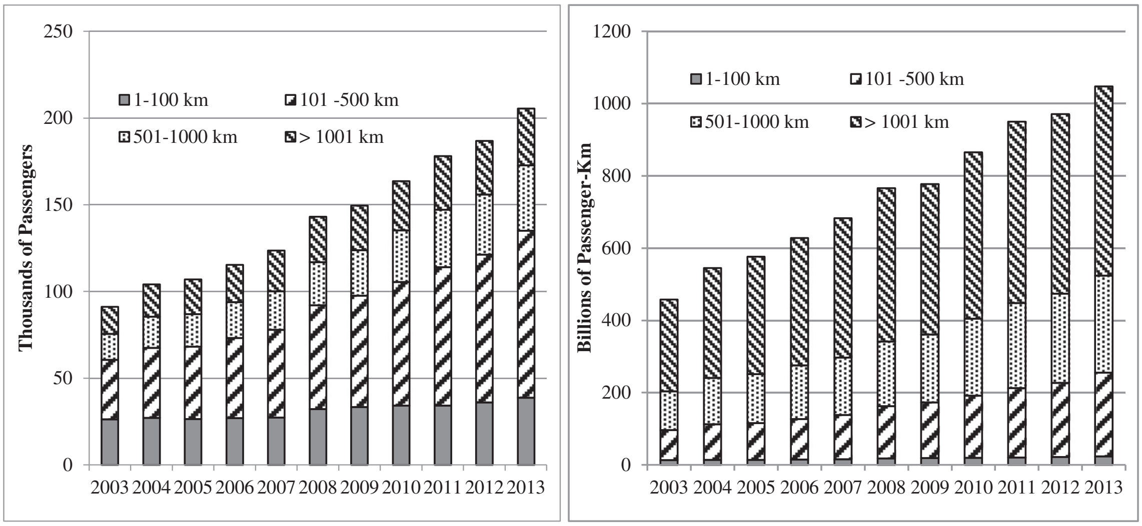


(a) Measured by Ridership (b) Measured by Passenger-km

Fig. 1. Passenger railway demand by distance traveled.
Source: National Bureau of Statistics of China.

HSR lines have been completed at different times. As a result, it is difficult to generalize about the effect of competition between HSR and domestic air transportation. To capture the completion effect more accurately, we need timelines of HSR opening schedules as well as matching air transport data to provide an informed empirical assessment of impacts, and to predict likely future effects.

This study is intended to meet that need by developing an improved evaluation method utilizing a comprehensive dataset. The study differs from previous work in a number of ways.

First, it evaluates both the national-level and regional-level impacts with a focus on two major HSR routes: Beijing-Shanghai (1318 km) and Beijing-Shenzhen (2372 km). In addition, the Wuhan-Guangzhou PDL (1039 km), which is a section of the Beijing-Shenzhen PDL and operated two years earlier than the entire line, is analyzed separately to elucidate the different spatial-temporal effects of HSR on air transportation service.

Second, the study utilizes a dataset that includes 767 domestic aviation OD pairs for the period 2001–2014 collected from the Bureau of Civil Aviation Development and Planning of China. This detailed OD data captures the entire spectrum of the development of the two major HSR routes, including the before, during and after stages. This means the assessment of competition will be more robust than previous studies because the effect of HSR on each specific air route can be related to actual opening dates.

The rest of the paper is organized as follows. Section 2 provides a literature review of the related work on HSR and air transportation, in which the gap of the existing knowledge on HSR's impact on domestic air travel is identified. Section 3 introduces the characteristics of competition between HSR and air transport in China while Section 4 introduces the conceptual modeling framework. Section 5 introduces methodology and data, which is followed by Section 6 with empirical results. Section 7 summarizes and concludes.

2. Literature review

The market interaction between HSR and air transportation has been studied extensively over recent years as can be seen in the summary of the relevant studies shown in Table 1, which was expanded upon the pioneering reviews by Albalate et al. (2015) and Wan et al. (2016). The classical approach involves an assessment from a supply perspective (Dobruszkes, 2011) or utilizing travel demand modeling (Behrens and Pels, 2012; Clever and Hansen, 2008; Cascetta et al., 2011; Pagliara et al., 2012; Park and Ha, 2006; Steer Davies Gleave, 2006), which suggest that the competition between HSR and air is limited to the medium-distance travel market. Givoni and Dobruszkes (2013) extended this thinking by suggesting the majority of the HSR demand is from induced demand and the substitution of demand from conventional trains, so that one-on-one comparisons with air are more complicated than first thought.

That approach opened up questions about the factors determine the level of competition and furthermore how the competition may vary spatially. Albalate and Bel (2012) indicated that HSR market share with respect to air transportation decreases with distance and its share becomes modest for routes beyond 650 km. On the supply side Albalate et al. (2015) conducted an econometric analysis based on a dataset of air services in Spain. Their study confirms that the supply of airline service measured in number of seats did reduce after the operation of HSR, however, when the supply of air service was measured in flight frequency, the result shows that air service did not suffer a significant reduction. On the demand side, Behrens and Pels (2012) assessed the competition between HSR and air using enplanement as a proxy. However, the issue has never been examined from both the supply and demand perspectives under a consistent modeling framework.

The burgeoning development of HSR in China has naturally attracted a rising interest from scholars who have used a variety of approaches to analyze the issue. For example, Fu et al. (2012), studied from an aggregate perspective of HSR and air, whereas Yang and Zhang (2012). Jiang and Zhang (2016) and Xia and Zhang (2016) used methodological perspectives that focused upon the socioeconomic outcomes of HSR and air competition as seen in traffic volumes, price, profits and welfare changes. In addition, some investigations were also conducted from a modal integration perspective using stated preference survey data with an objective to identify the market potential of the air and HSR integration in China (Li and Sheng, 2016).

Although these studies expanded the view on the competition between HSR and air, key questions related to the level of competition in both time and space remain unaddressed.

One step in that direction was taken by Wan et al. (2016) who used a dataset covering air transportation services in China, Japan and Korea during the period 1994–2012 using a difference-in-difference approach. Their study showed that the entries of HSR in China lead to a more significant decline in air service supply when measured by seat capacity than had occurred in Japan and Korea, after controlling for the speed of HSR. Although the result appears to be plausible, the findings are questionable due to the two issues.

First, the effect of the Chinese HSR services is likely to be

Table 1
Summaries of the literature using quantitative method to study the competition between HSR and air transportation.
Source: Author's revision based on the summaries of Albalate et al. (2015, 174) and Wan et al. (2016, 534–535).

Paper	Country	Data	Method	Results
Albalate et al. (2015)	Spain	2002–2010 in the case of flight frequencies 2002–2009 in the case of flight seat	Multivariate econometric regression	Airlines subject to competition from HSR do reduce the number of seats they offer on a given route. However, we also show that the frequency of air services on these route do not suffer a significant reduction
Behrens and Pels (2012)	UK, France	Trip-based cross-sectional survey data, 2003–2009	Multinomial and mixed logit models (five airport-airline pairs vs. HSR)	Observed stronger competition in the market than in other markets. The degree and pattern of intermodal competition depends on trip purpose
Campos and Gagnepain (2009)	France, the Netherlands	Price and market share, 2005	System of demand, pricing and cost functions (Traditional air, low-cost air, HSR, conventional train)	Simulation was conducted for the demand and pricing functions only. HSR price change has limited impact on airline demand
Cascetta et al. (2011)	Italy	Survey, March 2008	Nested logit mode choice model (HSR, conventional trains vs. cars)	Car users are generally inelastic to HSR travel time and cost
Pagliara et al. (2012)	Spain	Survey, February and March 2010	Multinomial and mixed logit models (HSR vs. air)	Market share taken by HSR was lower than expected. Price and frequency are the most important determinants in competition
Román et al. (2007)	Spain	Survey	Nested logit model (car, bus, train, air vs. HSR)	HSR is predicted to obtain limited market share (< 35%) when competing with air
Jiménez and Betancor (2012)	Spain	Route-level panel data, January 1999–December 2009	Impact of HSR entry captured by HSR entry dummy, route fixed effect captured by destination airport dummies, no time fixed effect	HSR entry leads to reduction of 17% in flight frequencies on average, except for the Madrid-Barcelona route, and the decline of air market shares was observed
Castillo-Manzano et al. (2015)	Spain	Time series monthly data, January 1996–December 2012	Estimate the substitution effect between HSR and air with dynamic linear regression	The rate of substitution dropped when new HSR lines with low population opened. Only 13.9% of the HSR passenger demand came from the air mode. There is no evidence that HSR has a strong network effect to attract air passengers
Gleave (2006)	Europe	Cross-sectional	Logit model used to predict passenger choice between rail and air	The fitted logit model is used as part of the simulation to predict future market share. Mixed results on rail market shares based on various scenarios
Clewlow et al. (2014)	Europe	Route-level panel data, 1995–2009	HSR impact is captured by rail travel time, no route fixed effect, no time fixed effect	Lower HSR travel time is associated with lower air passenger traffic volume
Dobruszkes et al. (2014)	Europe	Route-level cross-sectional data, January 2012	HSR impact is captured by HSR travel time and frequency	Lower HSR travel time has strong association with fewer airline frequencies and seats. Higher HSR frequency has limited impact on airline seats. Other HSR related variables are not statistically significant
Bilotkach et al. (2010)	Europe	Route-level panel data, May 2006–April 2007	HSR impact is captured by HSR dummy which equals to 1 if HSR service exists, no route fixed effect, no time fixed effect	HSR may have a positive pressure on airline flight frequencies based on the entire sample, but no statistically significant impact was found in short-haul routes subsamples (< 550 km)
Givoni and Rietveld (2009)	World	Route-level cross-sectional data, 2003	HSR impact is captured by a less-than-three-hour HSR dummy variable	No significant impact of HSR on aircraft size was found
Clever and Hansen (2008)	Japan	Intercity travel survey, 1995	Nested logit model, mode choice followed by terminal pair choice nested in each mode	Air only competes in markets with medium access/egress distance
Park and Ha (2006)	Korea	Survey	Logit model (air vs. HSR)	Large market share drop in air was predicted
Zhang et al. (2014)	China	Route-level panel data, 1st quarter of 2010–4th quarter of 2011	HSR impact is captured by HSR dummy equal to 1 if parallel HSR service exists for the same route, no route fixed effect, no time fixed effect	The existence of HSR service has strong negative impact on both airline market power and average airline yield
Wan et al. (2016)	China, Japan, Korea	1994–2012	Difference-in-difference	HSR entries lead to a more significant drop in airlines' seat capacity in China than in Japan and Korea
Wei et al. (2014)	China	Route-level panel data, June 20–August 3, 2011	Difference-in-difference	Mean airfare for the routes along the Jing-Hu HSR declined by 29% after the opening of the HSR

Table 2
Major HSR Services Operated during 2001–2014.
Source: data is collected from http://www.rail-transit.com/.

ID	HSR	Max speed (km/h)	Distance (km)	Opening date	Major impacted cities
1	Qinhuangdao-Shenyang North	200	404	10/12/2003	Shenyang
2	Hefei South-Nanjing South	250	166	4/18/2008	Hefei, Nanjing
3	Beijing South-Tianjin	350	119	8/1/2008	Beijing, Tianjin
4	Qingdao-Jinan	250	363	12/20/2008	Qingdao, Jinan
5	Shijiazhuang-Taiyuan	250	225	4/1/2009	Shijiazhuang, Taiyuan
6	Hefei-Wuhan	250	357	4/1/2009	Hefei, Wuhan
7	Dazhou-Chengdu	200	374	7/7/2009	Chengdu
8	Ningbo-Taizhou-Wenzhou	250	283	9/28/2009	Ningbo, Taizhou, Wenzhou
9	Wenzhou-Fuzhou	250	298	9/28/2009	Fuzhou, Wenzhou
10	Wuhan-Guangzhou	350	1069	12/26/2009	Wuhan, Changsha, Guangzhou
11	Zhengzhou-Xi'an	350	485	12/26/2009	Zhengzhou, Xi'an
12	Fuzhou-Xiamen	250	273	4/26/2010	Fuzhou, Xiamen
13	Shanghai-Nanjing	350	301	7/1/2010	Shanghai, Nanjing
14	Shanghai-Hangzhou	350	160	10/26/2010	Shanghai, Hangzhou
15	Beijing-Shanghai	350	1318	6/30/2011	Beijing, Tianjin, Jinan, Nanjing, Shanghai
16	Zhengzhou-Wuhan	350	536	9/28/2012	Zhengzhou, Wuhan
17	Harbin-Dalian	350	921	12/1/2012	Harbin, Changchun, Shenyang, Dalian
18	Beijing-Shijiazhuang	350	693	12/26/2012	Beijing, Shijiazhuang
19	Xiamen-Shenzhen	250	502	12/28/2013	Xiamen, Shenzhen
20	Taiyuan-Xi'an	250	570	7/1/2014	Taiyuan, Xi'an
21	Hangzhou-Changsha	350	933	12/10/2014	Hangzhou, Changsha

underestimated given that the research only included two-years after 2010. This also reflects the fact that the treated/control group ratio is very small. In fact, as illustrated in Table 2, there were only four major HSR PDLs (with a distance of over 400 km) in operation by the end of 2012 (excluding those opened in the fourth quarter of 2012). All these suggest that their estimation tends to be biased due to the limited number of HSRs included as part of their analysis. Second, difference-in-difference (DID) is not an appropriate method for the evaluation of HSR in China. One of the key assumptions of the DID approach is that the control group and the treated group should have parallel trends over time in the absence of the treatment. In effect, the approach is more appropriate to a short-term scenario. As discussed earlier, HSR development in China has spanned at least five years, or longer in some locations. The entire HSR network covers over 28 provinces and municipalities but many HSR routes began operation on different dates. As a result, it becomes quite challenging to separate the HSR effect from the control group if the DID approach is adopted. In sum, this review point to the need for a new approach that can accommodate the complex space and time context of the Chinese experience.

3. HSR and domestic air transport in China

Table 2 provides insight on the complex and staged evolution of the Chinese HSR network. To understand the impacts of that data on domestic air transportation, we need a similar perspective on evolution of domestic air travel. Over the recent past, domestic air transport demand grew exponentially, expanding from 6.8 million to 360 million between 2001 and 2014, while the supply, measured by annual flight frequency, increased from 1.9 million to 7.9 million over the same period. As can be seen in Fig. 2, the majority of this growth was concentrated upon travel between a few major cities, including Beijing, Shanghai, Guangzhou, Shenzhen and Chengdu, which have an annual enplanement over 35 million each in 2014.

Recognizing this spatial dimension in the growth in air travel demand provides a base to select intercity transport markets where competition with HSR can be meaningfully evaluated. Fig. 3 illustrates one approach to the issue.

Taking two long distance HSR routes and breaking them into segments, it is possible to study demand (passenger numbers) and supply (flights) over the period 2001 and 2014. The graphs show the response of demand and supply of domestic air service was substantial among different OD pairs after the entry of HSR. Fig. 3 provides data on outcomes on two lines, with links between cities enroute. Fig. 3(a) and (c) records results for the 968 km line between Wuhan and Guangzhou, the first long-distance trunk HSR line built where the service began on December 26, 2009. This line also connects Changsha in the middle and Shenzhen in the South. With a top speed of 300 km/h, travel time by HSR between Wuhan and Guangzhou has been reduced to 3.5 h. As shown in Fig. 3(a) and (c), both the demand and supply of the air service along this corridor experienced a substantial decline after the opening of HSR in December 2009. For instance, from 2009 to 2012, the air travel demand between Guangzhou - Changsha decreased by 67%, while flights declined by 55% and between Shenzhen - Changsha demand fell 68% while flights declined 53% (Chen and Haynes, 2015). Closer study of the data shows that the initial competitive effect of the HSR seems to have dampened down in recent years on the Guangzhou–Wuhan and Shenzhen–Wuhan links. Some similar responses are also observed in change in air travel and services along the Beijing-Shanghai corridor after the HSR began operation in June 2011 (see Fig. 3(b) and (d) where major declined are recorded on the links between Beijing - Nanjing, Shanghai - Tianjin, Beijing - Jinan, and Shanghai – Jinan. However, the competitive effect of the HSR on air travel from Beijing and Shanghai has been different. It has experienced a decline after the HSR operation, but that decline is not as intensive as on the other routes, and is showing a trend to recover its earlier level. This may be attributed to a very strong demand for intercity travel between Beijing and Shanghai due to the complex and high level economic and political functions of both cities, which makes this the busiest air route within China. Once again, on this line, there is some evidence of a shift back to air services in links between Shanghai and Tianjin and Beijing and Nanjing.

In sum, the simultaneous examination of the HSR and domestic air transportation shows that responses to HSR can be quite diverse due to the heterogeneous socioeconomic characteristics of the cities involved, and possibly over longer distances. Hence although it is generally true that the domestic air service may face an increasing substitution to HSR, the level of competition is likely to be different both temporally and spatially and we need an accurate understanding of those elements to make effective predictions.

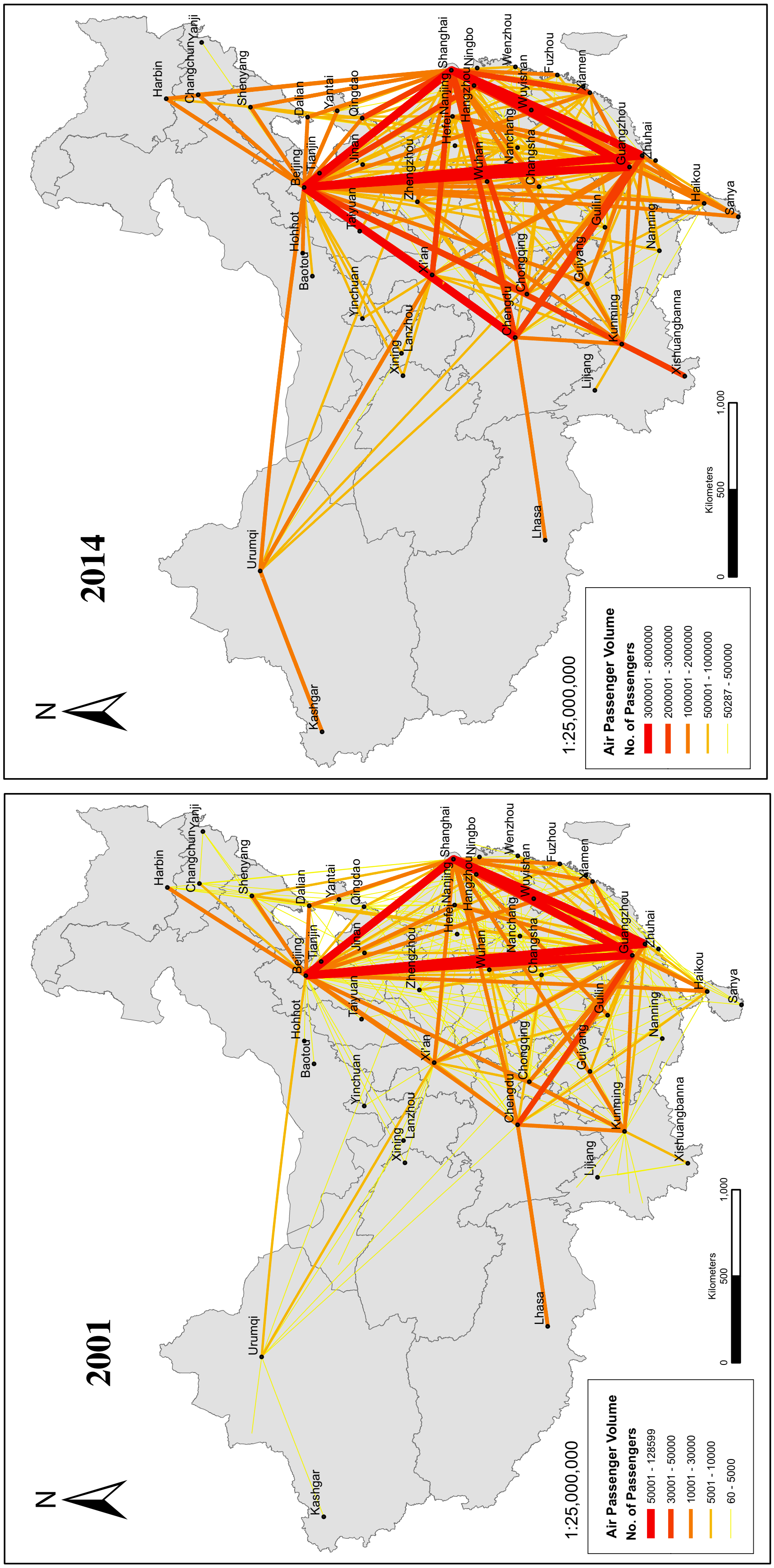


Fig. 2. Inter-city domestic aviation network in China: passenger volumes in 2001 and 2014.

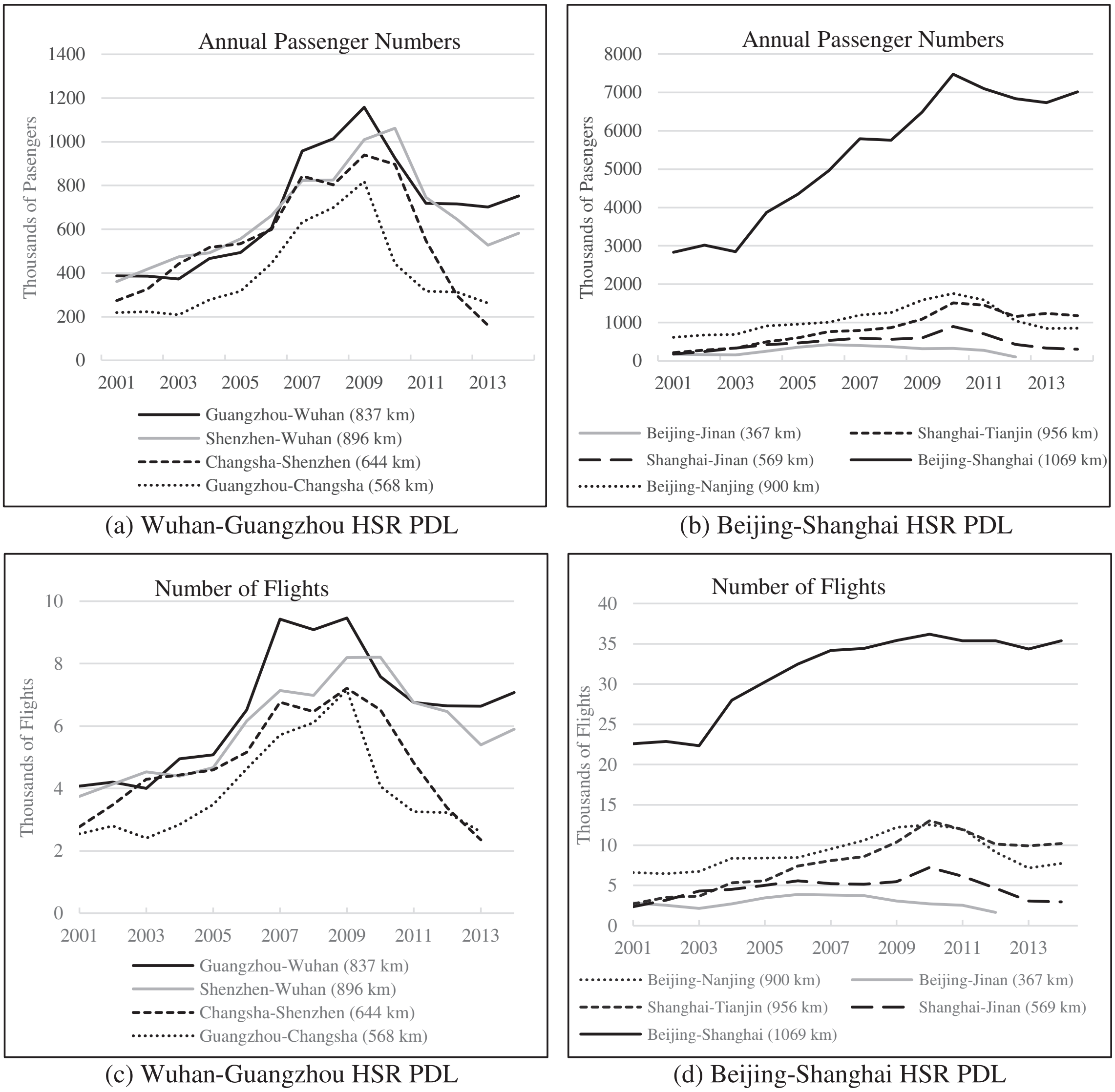
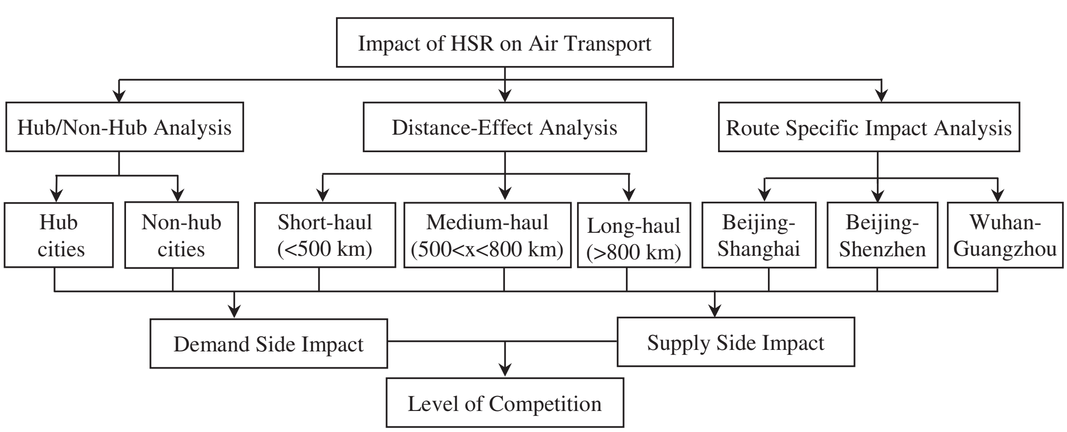


Fig. 3. Enplanement and flight numbers before and after the operation of HSR.

4. A conceptual framework to assess the impact of HSR on air transportation

A conceptual framework has been developed to show what is needed to effectively measure the level of competition between HSR and air transport by capturing the spatially heterogeneous pattern of the intercity travel demand, (see Fig. 4). Specifically, the impact is evaluated from three perspectives in a consistent modeling framework:

First, a hub/non-hub analysis is introduced to test whether or not the impacts of HSR on air transportation differ between hub cities and non-



Source: Author's illustration.

Fig. 4. Conceptual framework of the assessment of the impact of HSR on air transport.

hub cities. Earlier studies (e.g. Albalate et al. (2015)) have suggested that the level of impact of HSR on air service can be different given differences in city type. For example, in Europe, the reduction of air service in a hub city tends to be greater than in a non-hub city. Hence, it will be valuable to test whether such a hypothesis is valid in China.

Second, a distance-effect analysis is introduced. The motivation for this aspect is the inconsistent distance band adopted in the literature. Some studies suggested that HSR has a compelling advantage over automobile and air for a travel distance ranging from 160 to 800 km (Button, 2012), whereas other scholars pointed out the most effective distance for HSR to compete with air is 200–600 km (Vickerman, 1997) while Wan et al. (2016) adopted 500 km as the lower bound and 800 km as the upper bound. Scholars tend to agree that the optimal competitive distance of HSR is 3–4 h (Fu et al., 2012) beyond which air transport is favored by the majority of travelers. That still leaves a large distance for competition, especially at high speeds. So the 3–4 h band translates into 750–1000 km at 250 km/h but reaches out to 900–1200 km at 300 km/h. It is clear that distance is a key consideration here.

One should note that both the hub/non-hub analysis and the distance-effect analysis are essentially assessed at an aggregate-level with an objective to identify the general or average result. However, as shown above, within routes inter-city impacts can vary. So a regional-level assessment is introduced. Route specific impact analysis is also critical as the Chinese HSR system was implemented in different phases and served different regions at different times, so the analysis needs to limit the comparison of OD pairs to certain groups within the affected geographic boundaries. These results may also provide an opportunity to explore any change in the impact of HSR not only between regions, but over time.

5. Methodology and data

The assessment of HSR on the air service is implemented using a panel regression analysis. The modeling framework is based on Albalate et al. (2015) and built and extended with considerations of the demand for air service as well as a richer data range. The unit of observation is air service route-year for each city pair, in other words, an observation represents a specific OD city pair's air service in a given year. The primary data such as enplanement, flight frequencies and seat capacities are collected from the annual statistics of aviation publication *From a Statistical Look at the Civil Aviation* for the period 2001–2014. The raw data contains 792 domestic airline routes with a total number of 6263 observations. However, the dataset is unbalanced as quite a few air routes only have data statistics in one or two years. Hence, to achieve a consistent panel assessment, a data filtering process is implemented to exclude those air service routes with observations of less than a decade. The cleaned data after this filtering includes 3834 observations with 295 OD city pairs. The level of competition between HSR and air is measured by the estimated elasticity of demand and supply changes in air transportation after the operation of HSR through the following equations:

$$\ln(\text{Passenger}_{it}) = \alpha + \beta_1 \ln(\text{WPOP}_{it}) + \beta_2 \ln(\text{WGDPPC}_{it}) + \beta_3 \ln(\text{Distance}_i) + \beta_4 \text{Hub}_i + \beta_5 \text{HSR}_{it} + \beta_6 \text{Y03}_t + \beta_7 \text{Y08}_t + \text{trend} + \varepsilon_{it} \quad (1)$$

$$\ln(\text{Frequency}_{it}) = \alpha + \beta_1 \ln(\text{WPOP}_{it}) + \beta_2 \ln(\text{WGDPPC}_{it}) + \beta_3 \ln(\text{Distance}_i) + \beta_4 \text{Hub}_i + \beta_5 \text{HSR}_{it} + \beta_6 \text{Y03}_t + \beta_7 \text{Y08}_t + \text{trend} + \varepsilon_{it} \quad (2)$$

$$\ln(\text{Seat}_{it}) = \alpha + \beta_1 \ln(\text{WPOP}_{it}) + \beta_2 \ln(\text{WGDPPC}_{it}) + \beta_3 \ln(\text{Distance}_i) + \beta_4 \text{Hub}_i + \beta_5 \text{HSR}_{it} + \beta_6 \text{Y03}_t + \beta_7 \text{Y08}_t + \text{trend} + \varepsilon_{it} \quad (3)$$

where the dependent variables are number of enplanement (Passenger), number of flight (Frequency) and number of seats (Seat) offered by airlines serving route *i* in year *t*. Note that since all variables except the dummies are measured in logarithmical forms, the β estimate is interpreted as elasticity. The demand side impact of HSR on air transport is measured through Eq. (1), whereas the supply side impact is measured through Eqs. (2) and (3). The following explanatory variables are adopted following Albalate et al. (2015) and Wan et al. (2016):

Weighted population (WPOP): The variable is introduced to control for the demographic characteristic of a specific OD route that involves both origin and destination cities. Previous research suggests that the higher the weighted population of an air route, the larger both the demand and supply its air service.

Weighted GDP per capita (WGDPPC): Similarly, this variable is introduced to control for the regional economic characteristic at both the origin and destination of a certain route. The measurement is the annual real GDP of each city with an air transport service. It is expected that a higher GDP per capita weighted by population implies a stronger regional economic performance and household income, which is associated with a higher level of the demand and supply of air service. Both the population and GDP per capita data are collected from the National Statistics Bureau of China.

Distance: the variable reflects the Euclidean distance of an air route between origin and destination, which does not vary by time. As discussed earlier the expected influence of distance on air service supply in the face of HSR competition is imprecise varying in different studies and by type of air service. Based on Wan et al. (2016)'s finding, we tend to hypothesize that distance will have a negative statistical association with the demand and supply of air transport in China.

Hub: this is a dummy variable created to measure whether an air service either starts or ends at one of the four major air hub cities which are Beijing, Shanghai, Guangzhou and Chengdu. The air route that involves at least one hub city is expected to have a relative higher demand and supply of air service than other routes, ceteris paribus.

The four cities are selected as major air hubs in China based on a judgement given the following two considerations. First, the four cities were considered as major air hubs in previous studies, such as Zhang (1998) and Lin and Chen (2003). This is because each city serves as a major base for one particular airline (e.g. Beijing for Air China, Shanghai for China Eastern, Guangzhou for China Southern, and Chengdu for Sichuan Airline), which influences the number of connecting flights. Second, the role of a city as a hub in China is also strongly influenced by public policy directed at encouraging regional development. For instance, Chengdu's hub status relates to the strong government support implied in the implementation of the national strategy of the “One Belt, One Road” where Chengdu's location and function will be important (Yu and Chao, 2016). It is possible that the hub variable could play a part in sensitivity analysis in future research where the effect of changing the definition of an air hub (e.g. as a result of the new patterns in the air hub-and-spoke network system) on HSR demand could be investigated.

HSR: this is a dummy variable in which one represents air route with a parallel HSR service between a city pair. To achieve a robust estimation, the HSR variable incorporates the following considerations:

First, only direct HSR services connecting the origin and destination cities of an air route are considered. Second, given a realistic consideration of the competition between HSR and airline, we define an “effective” entry year of HSR as one year after the actual operation of the service began, counted after July 1 in each year (in other words, in the second half of a year).

Third, the HSR variable is coded manually based on its opening dates (illustrated in Table 2) and the related service route information is obtained from the official ticket reservation website of the Chinese Railway Corporation (www.12306.cn). As illustrated in Table 3, compared with the classical DID approach, the improved approach has a salient advantage of integrating the effects of different HSR routes, which helps capture the compound effects of HSRs, even if the services cover different cities and with different start dates. The treated group

Table 3
The improved measurement for the compound HSR effects.
Source: Author's illustration.

ID	Route	Year	Beijing-Shanghai HSR			Beijing-Shenzhen HSR			The improved approach
			Treated/control	Time effect	Combined HSR effect	Treated/control	Time effect	Combined HSR effect	
1	Beijing-Shanghai	2001	1	0	0	0	0	0	0
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮
1	Beijing-Shanghai	2011	1	1	1	0	0	0	1
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮
1	Beijing-Shanghai	2013	1	1	1	0	1	0	1
1	Beijing-Shanghai	2014	1	1	1	0	1	0	1
2	Beijing-Chengdu	2001	0	0	0	0	0	0	0
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮
2	Beijing-Chengdu	2011	0	1	0	0	0	0	0
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮
2	Beijing-Chengdu	2013	0	1	0	0	1	0	0
2	Beijing-Chengdu	2014	0	1	0	0	1	0	0
3	Beijing-Guangzhou	2001	0	0	0	1	0	0	0
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮
3	Beijing-Guangzhou	2011	0	1	0	1	0	0	0
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮
3	Beijing-Guangzhou	2013	0	1	0	1	1	1	1
3	Beijing-Guangzhou	2014	0	1	0	1	1	1	1

Table 4
Descriptive statistics.
Source: Author's summary based on the dataset.

Variable	Data used for HSR impact estimation 2001–2014 (no. of obs. is 2834)			
	Mean	SD.	Min	Max
No. of flights	4382	4094	208	36,169
No. of enplanement	519,933	607,118	37,041	7,473,355
No. of seats	691,071	757,532	14,781	8,607,194
OD distance (km)	1095	536	325	3287
HSR	0.03	0.16	0	1
OD contains a hub city	0.44	0.50	0	1
Weighted population	944	604	69	3319
Weighted GDP per capita[a]	65,519	47,821	4000	419,756
Year 2003	0.07	0.25	0	1
Year 2008	0.08	0.27	0	1
Trend	7.61	3.89	1	14

[a] Measured in Chinese *Yuan*. A U.S. dollar approximately equals to 6.7 Chinese *Yuan*.

and the control group are also effectively separated with the considerations of spatial and temporal evolution of various HSR services.

Year 2003 and Year 2008: both are dummy variables created to capture major events that may affect air transportation demand and supply. Specifically, Year 2003 is introduced to control for the breakout of the severe acute respiratory syndrome (SARS), which is expected to have had a dampening effect on the domestic air service. Conversely, Year 2008 is introduced to capture the effect of the Beijing Olympic Games, which is expected to have a positive effect on the air service demand.

Trend: the variable is introduced to capture the overall growth of the demand and supply of domestic air services explained by time (everything not observable but that is likely to be increasing or decreasing with time).

The characteristics of data used for HSR impact estimation are summarized in Table 4.

6. Empirical findings

6.1. Aggregate impacts and distance level impacts

Table 5 shows the panel regression results of the impact of HSR on the demand for domestic air service, measured by number of passengers after controlling for other factors using both fixed effect and random effect estimators. Because the dataset is an unbalanced panel, the Hausman test is generally ineffective to determine which estimator is more preferred due to the violation of asymptotic assumptions. Instead, the Sargen-Hansen test using the Stata command *xtoverid* is adopted. The test is known as a generalized test for over-identifying restrictions between fixed and random effects of a panel data model. A significant test value suggests that the extra restrictions imposed by the random effect model are rejected, hence a fixed effect estimator is preferred, otherwise, a random effect is preferred. Overall, the results across different models suggest that fixed effect estimators are generally more robust.

The analysis as shown from model 1 to 12 reveal that population, regional GDP per capita has positive influences on the demand variations of domestic air transport as expected. Statistically significant influences of the distance variable and the hub variable are also confirmed. The result suggests that the longer the distance between the origin and destination, the less the frequency of air service. At the same time, an air service that either departs or lands at a hub airport is likely to have a relatively higher demand than other air services. The dummy variables representing two special events are also found to be statistically significant in most of the models. The signs of the statistical significant estimates are generally consistent, which confirms that SARS in 2003 did have a negative effect on the domestic air demand, whereas the Beijing Olympic Game hosted in 2008 had a positive influence on the domestic air service demand.

The influences of HSR on air transport demand are found to be statistically significant across all the models, which indicate that the impact results are generally consistent and robust. A closer comparison of the estimates shows that the level of HSR's impact on air demand does vary slightly depending on the specific scale of assessment. For instance, although the estimated coefficient ranges from -0.331 to -0.329 at the national level in model 1 and 2, the values are found to be relatively higher among air routes involving a hub city than routes

Table 5
Regression results: aviation demand measured by number of passengers.

Model	All city-pairs		Hub city-pair		Non-hub city-pair		Dis. ≤ 500 km		500 km < Dis. ≤ 800 km		Dis. > 800 km	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
lwpop	0.250**	0.306***	−0.287	0.437**	0.512***	0.266***	0.491*	0.172	0.492***	0.361***	0.683***	0.439***
	(2.39)	(5.63)	(−0.87)	(2.50)	(3.97)	(4.93)	(1.77)	(0.87)	(2.71)	(4.52)	(4.59)	(5.98)
lwgdppc	0.656***	0.583***	0.483***	0.519***	0.900***	0.528***	1.281***	0.982***	0.887***	0.484***	0.467***	0.552***
	(11.65)	(13.23)	(6.60)	(7.80)	(10.33)	(9.95)	(6.09)	(5.37)	(8.18)	(6.81)	(7.02)	(10.09)
lkm		−0.144**		−0.124		−0.156**		−1.496		−0.146		−0.383***
		(−2.37)		(−1.22)		(−2.27)		(−1.29)		(−0.44)		(−3.28)
Hub		0.668***						0.433		0.621***		0.677***
		(10.08)						(1.28)		(5.68)		(8.44)
HSRs	−0.331***	−0.329***	−0.400***	−0.390***	−0.254***	−0.280***	−0.199**	−0.234**	−0.416***	−0.442***	−0.276***	−0.254***
	(−10.35)	(−10.22)	(−12.02)	(−11.55)	(−4.10)	(−4.43)	(−2.07)	(−2.41)	(−7.42)	(−7.75)	(−6.83)	(−6.22)
y2003	−0.084***	−0.088***	−0.126***	−0.121***	−0.056**	−0.069**	−0.121*	−0.135**	−0.088**	−0.103***	−0.079***	−0.075***
	(−4.38)	(−4.54)	(−5.14)	(−4.85)	(−1.98)	(−2.38)	(−1.80)	(−1.98)	(−2.47)	(−2.80)	(−3.42)	(−3.21)
y2008	0.044**	0.045**	0.012	−0.003	0.071***	0.079***	0.142**	0.151**	0.059*	0.070**	0.028	0.026
	(2.53)	(2.56)	(0.50)	(−0.12)	(2.84)	(3.11)	(2.28)	(2.39)	(1.80)	(2.07)	(1.37)	(1.27)
Trend	0.020**	0.029***	0.055***	0.042***	−0.023*	0.033***	−0.116***	−0.070***	−0.026	0.033***	0.051***	0.042***
	(2.32)	(4.40)	(5.43)	(4.43)	(−1.69)	(4.10)	(−3.68)	(−2.61)	(−1.59)	(3.03)	(5.22)	(5.18)
Constant	3.806***	4.823***	9.530***	5.070***	−0.472	5.723***	−3.594	10.204	0.008	5.476**	2.710**	5.899***
	(3.78)	(6.59)	(4.31)	(3.47)	(−0.33)	(6.89)	(−1.05)	(1.43)	(0.00)	(2.40)	(2.12)	(5.26)
Effect	Fixed	Random	Fixed	Random	Fixed	Random	Fixed	Random	Fixed	Random	Fixed	Random
Hausman test	3.69		15.67**		29.08***		8.35		25.28**		6.07	
Sargan-Hansen	139.252***		72.526***		134.312***		17.946**		73.401***		100.533***	
No of obs.	3830	3830	1672	1672	2158	2158	336	336	1006	1006	2488	2488
R-squared	0.729	0.729	0.805	0.804	0.677	0.674	0.486	0.483	0.718	0.713	0.777	0.776

Note: T-statistics in parentheses. *, **, and *** denote significance at the 10, 5 and 1 percent levels, respectively.

that do not involve any air hub, ceteris paribus. The finding confirms that the level of competition between HSR and air transportation tends to be higher among major cities, especially those serve as a regional hub of air transportation, which is consistent with Button (2012).[1]

The results of the disaggregate level assessments are summarized in model 7–12, with a differentiation in the spatial scale of system operation. It is clear that the impact of HSR on the domestic air transport demand does vary spatially given the different geographic ranges being specified. Generally speaking, the impacts are found to be the largest when the distance of assessment is limited to the range of 500–800 km. The estimated coefficients in the fixed and the random models are −0.416 and −0.442. These can be interpreted as the opening of a HSR between cities ranging between 500 and 800 km apart is associated with an decline in the corresponding air travel demand on that link by 34% $(100 * (\text{EXP}(-0.416) - 1))$ and 35.7% $(100 * (\text{EXP}(-0.442) - 1))$, respectively. Conversely, the negative impacts of HSR on air travel demand decrease when the travel distance is either below 500 km or above 800 km, which suggests that the competition between HSR and air tends to be less fierce beyond the range of 500–800 km.

The supply side results are displayed in Tables 6 and 7, which summarize the impacts of HSR on the domestic air service supply measured in number of flights and seat capacities, respectively. The results are generally consistent with the demand side results in terms of both the significance and values of estimates for the control variables. The influences of HSR on the air service supply are also found to be statistically significant, but with different estimates across each model. Specifically, when comparing the results across the fixed effect models, the national level assessment shows that the impacts of HSR on the domestic flight number and seats are −0.283 and −0.327, whereas the estimates were found to be −0.339 and −0.382 when the dataset only include hub city-pairs, and −0.145 and −0.196 when only non-hub city-pairs are included, respectively. Models 19-24 and 31-36 show that HSR's effects on flight frequency and flight seat capacity vary by distance of travel. Again the statistically significant estimates are generally found to be relatively higher when the distance ranges between 500 and 800 km. These findings are consistent with the enplanement measures, which further confirms that the competition between HSR and air tends to concentrate on the medium distance market.

6.2. Regional impacts of specific HSR routes

Tables 8 to 10 summarizes the impact of HSR on the air service demand and supply at the regional scale with focuses on four specific HSR cases: Beijing-Shanghai PDL, Beijing-Shenzhen PDL, Wuhan-Guangzhou PDL and an aggregate case with the combinations of the Beijing-Shanghai PDL and Beijing-Shenzhen PDL. One should note that although the sample size is substantially reduced given the fact that only the relevant OD city pairs that overlap with the corresponding HSR service route are included in each specific assessment, the overall R-squared values remain at reasonable levels, which demonstrates the robustness of the estimations. The exclusion of irrelevant OD city pairs helps eliminate the interference from uncontrolled effects, such as effects from other HSR services. In addition, the variables measuring the distance of each OD pair and whether a hub airport is involved are also excluded due to their time-invariant characteristics.

Overall, the results show that HSR's impact on domestic air transportation does vary significantly by route. After controlling for the effects of demographic and economic characteristics, as well as the effects from SARS, the Beijing Olympic Game and time trend, the estimated coefficients of HSR on the domestic air transportation demand are found to be statistically significant within a range from −0.41 to −0.598. With regard to the estimates on the supply measures, the coefficients are found to range from −0.253 to −0.462 and −0.274 to

[1] One may have an impression from Section 3 that smaller regional centers (e.g. Wuhan) may have experienced more dramatic impacts from HSR initiation than larger hubs. These somewhat contradictory results can be reconciled from the following three respects: First, a comparison of the percent change of air demand between Sections 3 and 6 doesn't make sense because the former was based on descriptive statistics, whereas the latter was derived from econometric analysis. The magnitude of impact from econometric analysis is subject to various factors, such as model specifications, control variables and estimation methods being introduced. Second, the statement refers to a city-pair rather than a single city. The result is derived from the regression analysis, which should only be interpreted as mean estimates based on the entire sample. Hence, a city-pair involves at least one hub city is a sufficient, but not necessary condition for the OD pair to have a high level of HSR-air competition.

Table 6
Regression results: aviation service supply measured by number of flights.

Model	All city-pairs		Hub city-pair		Non-hub city-pair		Dis. ≤ 500 km		501 km < Dis. ≤ 800 km		Dis. > 800 km	
	(13)	(14)	(15)	(16)	(17)	(18)	(19)	(20)	(21)	(22)	(23)	(24)
lwpop	0.009	0.252***	−0.109	0.462***	0.180	0.237***	−0.460	−0.216	0.159	0.310***	0.762***	0.455***
	(0.09)	(5.06)	(−0.36)	(2.93)	(1.56)	(4.61)	(−1.61)	(−1.16)	(1.04)	(4.16)	(5.77)	(6.77)
lwgdppc	0.576***	0.526***	0.251***	0.326***	0.810***	0.510***	0.652***	0.564***	0.878***	0.503***	0.403***	0.497***
	(11.27)	(13.06)	(3.73)	(5.33)	(10.37)	(10.25)	(3.02)	(3.15)	(9.62)	(7.80)	(6.81)	(10.08)
lkm		−0.296***		−0.254***		−0.332***		−1.511		−0.224		−0.533***
		(−5.27)		(−2.79)		(−5.01)		(−1.48)		(−0.70)		(−4.94)
Hub		0.596***						0.611**		0.506***		0.598***
		(9.78)						(2.02)		(4.87)		(8.09)
HSR	−0.283***	−0.277***	−0.339***	−0.325***	−0.145***	−0.157***	−0.138	−0.136	−0.280***	−0.298***	−0.285***	−0.264***
	(−9.76)	(−9.47)	(−11.05)	(−10.42)	(−2.61)	(−2.77)	(−1.40)	(−1.38)	(−5.93)	(−6.16)	(−7.94)	(−7.25)
y2003	−0.043**	−0.046***	−0.105***	−0.097***	−0.003	−0.015	−0.099	−0.106	−0.024	−0.040	−0.043**	−0.039*
	(−2.45)	(−2.59)	(−4.61)	(−4.20)	(−0.12)	(−0.57)	(−1.43)	(−1.52)	(−0.81)	(−1.27)	(−2.13)	(−1.89)
y2008	−0.008	−0.009	0.015	0.002	−0.020	−0.013	0.122*	0.120*	−0.030	−0.022	−0.013	−0.015
	(−0.52)	(−0.58)	(0.71)	(0.11)	(−0.88)	(−0.58)	(1.91)	(1.86)	(−1.08)	(−0.78)	(−0.73)	(−0.81)
Trend	0.019**	0.023***	0.059***	0.043***	−0.011	0.031***	−0.034	−0.027	−0.038***	0.014	0.047***	0.037***
	(2.53)	(3.88)	(6.41)	(4.96)	(−0.93)	(4.03)	(−1.06)	(−1.02)	(−2.71)	(1.42)	(5.36)	(5.03)
Constant	1.612*	2.241***	6.054***	3.155**	−2.048	2.706***	4.215	12.439**	−2.202	1.703	−1.828	2.807***
	(1.76)	(3.34)	(2.97)	(2.39)	(−1.60)	(3.44)	(1.20)	(1.97)	(−1.41)	(0.78)	(−1.61)	(2.73)
Effect	Fixed	Random	Fixed	Random	Fixed	Random	Fixed	Random	Fixed	Random	Fixed	Random
Hausman test	13.34**		24.59***		35.64***		4.92		47.41***		14.35**	
Sargan-Hansen	151.937***		83.165***		131.160***		14.526**		88.552***		112.821***	
No of obs.	3830	3830	1672	1672	2158	2158	336	336	1006	1006	2488	2488
R-squared	0.711	0.710	0.749	0.748	0.697	0.694	0.321	0.316	0.715	0.708	0.778	0.777

Note: T-statistics in parentheses. *, **, and *** denote significance at the 10, 5 and 1 percent levels, respectively.

−0.707 when the air service supply is measured in flight numbers and seat capacity, respectively.

6.3. Comparison of impacts

Table 11 summarizes the percent change in the demand and supply of the domestic air transport after the entry of HSR. Overall, the opening of HSR had a significant influence on its domestic air services. The general impact on demand is around 28%, whereas the impact on the supply are around 24% and 28%, measured by flight frequency and seat capacity, respectively. The negative impacts slightly increase about 3–5% if the competition occurs on routes involving major hub cities, whereas the negative impacts reduce by 6 to 10% if the competition occurs on routes that do not involve a hub city.

The negative impacts of HSR on air travel are much larger when the competing distance ranges from 500 to 800 km. Within such a distance range, the air travel demand is expected to decline by approximately 34% due to the operation of HSR, but the negative impacts would be

Table 7
Regression results: aviation services measured by number of seats.

Model	All city-pairs		Hub city-pair		Non-hub city-pair		Dis. ≤ 500 km		501 km < Dis. ≤ 800 km		Dis. > 800 km	
	(25)	(26)	(27)	(28)	(29)	(30)	(31)	(32)	(33)	(34)	(35)	(36)
lwpop	0.205**	0.307***	0.221	0.572***	0.373***	0.260***	0.043	−0.043	0.205	0.324***	0.875***	0.489***
	(2.05)	(5.84)	(0.65)	(3.27)	(3.22)	(5.08)	(0.16)	(−0.24)	(1.25)	(4.17)	(5.98)	(6.74)
lwgdppc	0.707***	0.616***	0.318***	0.410***	0.962***	0.570***	0.989***	0.775***	1.060***	0.603***	0.486***	0.565***
	(13.16)	(14.52)	(4.17)	(5.98)	(12.29)	(11.44)	(4.91)	(4.49)	(10.77)	(8.86)	(7.43)	(10.47)
lkm		−0.198***		−0.155		−0.232***		−1.553		−0.164		−0.430***
		(−3.34)		(−1.54)		(−3.50)		(−1.47)		(−0.50)		(−3.72)
Hub		0.612***						0.571*		0.514***		0.626***
		(9.51)						(1.83)		(4.78)		(7.89)
HSR	−0.327***	−0.327***	−0.382***	−0.367***	−0.174***	−0.196***	−0.194**	−0.212**	−0.315***	−0.339***	−0.345***	−0.324***
	(−10.74)	(−10.63)	(−11.02)	(−10.43)	(−3.11)	(−3.43)	(−2.10)	(−2.30)	(−6.17)	(−6.46)	(−8.66)	(−8.05)
y2003	−0.048***	−0.053***	−0.118***	−0.109***	−0.004	−0.018	−0.113*	−0.124*	−0.041	−0.059*	−0.043*	−0.041*
	(−2.60)	(−2.85)	(−4.58)	(−4.21)	(−0.14)	(−0.69)	(−1.76)	(−1.91)	(−1.26)	(−1.75)	(−1.92)	(−1.77)
y2008	−0.023	−0.021	−0.002	−0.012	−0.032	−0.023	0.092	0.096	−0.033	−0.023	−0.031	−0.032
	(−1.38)	(−1.28)	(−0.08)	(−0.49)	(−1.44)	(−0.99)	(1.54)	(1.60)	(−1.10)	(−0.74)	(−1.54)	(−1.54)
Trend	0.007	0.019***	0.052***	0.035***	−0.024**	0.033***	−0.067**	−0.037	−0.050***	0.014	0.039***	0.032***
	(0.91)	(2.95)	(4.94)	(3.63)	(−1.98)	(4.37)	(−2.24)	(−1.48)	(−3.30)	(1.35)	(4.00)	(3.96)
Constant	3.977***	5.256***	8.142***	5.885***	0.129	6.175***	2.479	14.290**	0.580	5.092**	1.609	6.169***
	(4.14)	(7.43)	(3.53)	(4.00)	(0.10)	(7.85)	(0.75)	(2.19)	(0.34)	(2.27)	(1.28)	(5.56)
Effect	Fixed	Random	Fixed	Random	Fixed	Random	Fixed	Random	Fixed	Random	Fixed	Random
Hausman test	9.48		16.59**		47.12***		5.76		54.08***		11.87*	
Sargan-Hansen	145.502***		69.221***		152.695***		15.686**		96.543***		105.743***	
No of obs.	3830	3830	1672	1672	2158	2158	336	336	1006	1006	2488	2488
R-squared	0.725	0.724	0.723	0.722	0.737	0.733	0.499	0.497	0.747	0.739	0.756	0.755

Note: T-statistics in parentheses. *, **, and *** denote significance at the 10, 5 and 1 percent levels, respectively.

Table 8
Regression results by different HSR lines: aviation demand is measured by number of passengers.

HSR line	Beijing-Shanghai PDL		Beijing-Shenzhen PDL		Wuhan-Guangzhou PDL[a]		Aggregate of the two PDLs	
Model	(37)	(38)	(39)	(40)	(41)	(42)	(43)	(44)
lwpop	− 11.174***	− 7.793***	1.527***	2.033***	4.012	2.130***	1.178**	1.472***
	(− 3.81)	(− 2.84)	(2.81)	(5.74)	(1.44)	(3.98)	(2.42)	(3.83)
lwgdppc	1.804***	1.583***	0.381	0.857***	1.244	1.436***	0.405	0.582**
	(3.60)	(3.09)	(1.20)	(3.31)	(1.17)	(3.60)	(1.61)	(2.45)
HSR	− 0.410***	− 0.436***	− 0.446***	− 0.377***	− 0.598***	− 0.593***	− 0.488***	− 0.458***
	(− 2.88)	(− 2.96)	(− 5.05)	(− 4.50)	(− 3.65)	(− 3.45)	(− 6.39)	(− 6.16)
y2003	− 0.045	− 0.056	− 0.127	− 0.094	− 0.081	− 0.082	− 0.128*	− 0.115
	(− 0.33)	(− 0.39)	(− 1.46)	(− 1.07)	(− 0.46)	(− 0.43)	(− 1.68)	(− 1.51)
y2008	0.252	0.160	0.065	0.040	0.169	0.176	0.027	0.018
	(1.63)	(1.03)	(0.79)	(0.48)	(0.97)	(0.94)	(0.37)	(0.24)
Trend	− 0.040	− 0.039	0.030	− 0.049	− 0.136	− 0.148**	0.036	0.005
	(− 0.59)	(− 0.57)	(0.56)	(− 1.15)	(− 0.86)	(− 2.16)	(0.86)	(0.14)
Constant	72.582***	51.211***	− 1.158	− 9.329**	− 25.908	− 15.733**	0.841	− 2.939
	(3.93)	(2.96)	(− 0.19)	(− 2.13)	(− 1.40)	(− 2.20)	(0.17)	(− 0.70)
Effect	Fixed	Random	Fixed	Random	Fixed	Random	Fixed	Random
Hausman test	10.70*		8.06		0.37		5.05	
Sargan-Hansen test	7.742*		10.639		N/A[b]		7.568	
No. of obs.	68	68	149	149	52	52	217	217
R-squared	0.677	0.670	0.718	0.714	0.543	0.538	0.671	0.670

Note: T-statistics in parentheses. *, **, and *** denote significance at the 10, 5 and 1 percent levels, respectively.
[a] This is a section of the Beijing-Shenzhen PDL. It was opened in service on December 26, 2009, which is almost two years earlier than the formal operation of the whole line between Beijing and Shenzhen.
[b] No Sargan-Hansen result calculated due to the lack of variance in the panel-specific intercepts because of a small sample size.

only around 18% on distances below 500 km and 24% where the distance is over 800 km.

When specific routes are analyzed, it is apparent that substantial negative impacts have been felt on the Beijing-Shanghai PDL and Beijing-Shenzhen PDL. These have an average effect of a 38.6% decline in enplanement, a 29.5% decline in flight numbers and a 37.2% decline in seat capacity. The relatively larger amount of reduction in seat capacity as compared with the reduction in flight numbers may reflect that corresponding strategies, such as replacing large jets with smaller ones, have been taken by airlines to compete with the emerging HSR services.

7. Conclusions

Although the impact of HSR on air transportation has been extensively studied in Europe, the understanding of the outcome of completion in the recently constructed and very much larger Chinese HSR has attracted less comprehensive attention. This is not surprising given the fact that the system is still new and many routes are still under development. This study filled this gap by concentrating on demand and supply perspectives of HSR and air transport for inter-city routes that were operating during the period 2001–2014. The comprehensive analytical framework that was developed enabled an

Table 9
Regression Results by Different HSR Lines: Aviation Services measured by Number of Flights.

HSR line	Beijing-Shanghai PDL		Beijing-Shenzhen PDL		Wuhan-Guangzhou PDL[a]		Aggregate of the two PDLs	
Model	(45)	(46)	(47)	(48)	(49)	(50)	(51)	(52)
lwpop	− 8.675***	− 5.563**	1.162**	1.548***	2.020	1.818***	1.193***	1.347***
	(− 3.57)	(− 2.48)	(2.61)	(5.81)	(0.98)	(4.34)	(2.98)	(4.37)
lwgdppc	1.340***	1.137***	0.043	0.528***	0.758	1.062***	0.203	0.350*
	(3.23)	(2.67)	(0.16)	(2.59)	(0.96)	(3.40)	(0.98)	(1.80)
HSR	− 0.253**	− 0.278**	− 0.327***	− 0.259***	− 0.462***	− 0.434***	− 0.349***	− 0.326***
	(− 2.14)	(− 2.26)	(− 4.51)	(− 3.76)	(− 3.80)	(− 3.23)	(− 5.55)	(− 5.34)
y2003	− 0.029	− 0.040	− 0.110	− 0.076	− 0.075	− 0.065	− 0.099	− 0.088
	(− 0.25)	(− 0.33)	(− 1.55)	(− 1.05)	(− 0.56)	(− 0.43)	(− 1.58)	(− 1.41)
y2008	0.238*	0.154	0.060	0.035	0.148	0.136	0.027	0.021
	(1.86)	(1.19)	(0.88)	(0.50)	(1.15)	(0.93)	(0.46)	(0.34)
Trend	− 0.042	− 0.042	0.059	− 0.019	− 0.065	− 0.109**	0.034	0.010
	(− 0.76)	(− 0.72)	(1.35)	(− 0.58)	(− 0.55)	(− 2.03)	(0.99)	(0.32)
Constant	55.420***	35.754**	0.070	− 7.413**	− 12.645	− 14.441***	− 1.783	− 4.312
	(3.62)	(2.53)	(0.01)	(− 2.21)	(− 0.92)	(− 2.59)	(− 0.44)	(− 1.27)
Effect	Fixed	Random	Fixed	Random	Fixed	Random	Fixed	Random
Hausman test	11.02*		12.00**		0.08		5.37	
Sargan-Hansen test	8.334**		13.764**		N/A[b]		9.555	
No. of obs.	68	68	149	149	52	52	217	217
R-squared	0.553	0.541	0.693	0.685	0.545	0.543	0.617	0.616

Note: T-statistics in parentheses. *, **, and *** denote significance at the 10, 5 and 1 percent levels, respectively.
[a] This is a section of the Beijing-Shenzhen PDL. It was opened in service on December 26 2009, which is almost two years earlier than the formal operation of the whole line between Beijing and Shenzhen.
[b] No Sargan-Hansen result is calculated due to the lack of variance in the panel-specific intercepts because of a small sample size.

Table 10
Regression Results by Different HSR Lines: Aviation Services measured by Number of Seats.

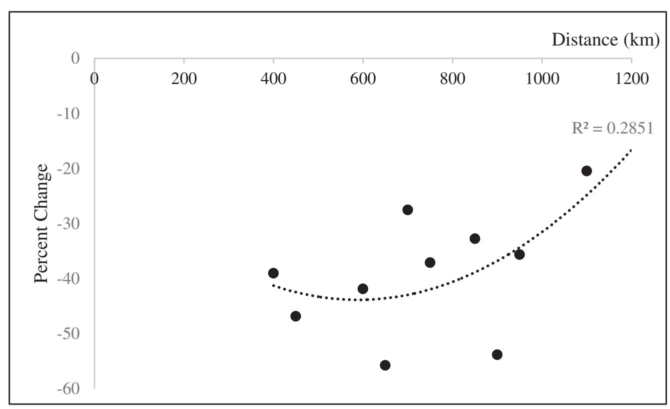
HSR Line	Beijing-Shanghai PDL		Beijing-Shenzhen PDL		Wuhan-Guangzhou PDL[a]		Aggregate of the two PDLs	
Model	(53)	(54)	(55)	(56)	(57)	(58)	(59)	(60)
lwpop	− 1.871	1.805	1.358***	1.788***	2.506	1.728***	1.387**	1.582***
	(− 0.30)	(0.38)	(3.08)	(5.44)	(1.24)	(3.96)	(2.11)	(3.40)
lwgdppc	0.314	0.076	0.161	0.543**	0.731	1.162***	0.203	0.446
	(0.29)	(0.07)	(0.63)	(2.40)	(0.94)	(3.57)	(0.60)	(1.44)
HSR	− 0.707**	− 0.735**	− 0.330***	− 0.274***	− 0.466***	− 0.435***	− 0.465***	− 0.431***
	(− 2.30)	(− 2.45)	(− 4.60)	(− 3.93)	(− 3.91)	(− 3.11)	(− 4.50)	(− 4.35)
y2003	− 0.117	− 0.129	− 0.109	− 0.083	− 0.060	− 0.046	− 0.110	− 0.092
	(− 0.39)	(− 0.44)	(− 1.55)	(− 1.16)	(− 0.46)	(− 0.30)	(− 1.07)	(− 0.89)
y2008	0.052	− 0.047	0.066	0.046	0.141	0.129	0.039	0.028
	(0.16)	(− 0.15)	(0.98)	(0.67)	(1.12)	(0.85)	(0.40)	(0.28)
Constant	0.063	0.063	0.046	− 0.018	− 0.061	− 0.119**	0.041	0.002
	(0.44)	(0.45)	(1.04)	(− 0.49)	(− 0.53)	(− 2.12)	(0.72)	(0.03)
Trend	23.345	0.128	2.611	− 4.100	− 10.539	− 9.913*	1.935	− 1.857
	(0.59)	(0.00)	(0.52)	(− 1.04)	(− 0.78)	(− 1.71)	(0.29)	(− 0.35)
Effect	Fixed	Random	Fixed	Random	Fixed	Random	Fixed	Random
Hausman test	0.76		12.46*		0.31		3.72	
Sargan-Hansen test	1.061		13.294**		N/A[b]		5.886	
No. of obs.	68	68	149	149	52	52	217	217
R-squared	0.182	0.177	0.730	0.726	0.576	0.572	0.417	0.415

Note: T-statistics in parentheses. *, **, and *** denote significance at the 10, 5 and 1 percent levels, respectively.
[a] This is a section of the Beijing-Shenzhen PDL. It was opened in service on December 26 2009, which is almost two years earlier than the formal operation of the whole line between Beijing and Shenzhen.
[b] No Sargan-Hansen result is calculated due to the lack of variance in the panel-specific intercepts because of a small sample size.

assessment of the impacts of HSR on domestic air service from both aggregate and disaggregate perspectives, allowing for capturing the effects of hub versus non-hub cities, and distance between cities, as well as insight on specific routes.

The research findings show that the currently established HSR services have a significant substitutional effect on domestic air transport in China. That effect varies across different HSR routes, travel distances and city types. Focusing upon the effects of distance, the results can be represented as the inverse U-shape curve in Fig. 5. The negative impacts on air service are the greatest between cities located from 500 to 800 km apart. However, there are important differences in different parts of the country as the analysis found a 45% decline in air services between cities in the Wuhan-Guangzhou HSR corridor, whereas it was 33.6% for the Beijing-Shanghai HSR.

The strong substitution effect of HSR for air service found in this study is consistent with previous studies of the Chinese HSR system, such as Fu et al., (2012), Zhang et al., (2014), Wei et al. (2014) and Wan et al. (2016). They are also consistent with early studies that focused on European HSR systems, such as Albalate et al. (2015), Jiménez and Betancor (2012), Castillo-Manzano et al. (2015), and Clever and



Each dot represents an estimation from a regression model based on the given O-D samples that fall in the corresponding distance range.
Source: Author's calculation.

Fig. 5. Relationship between HSR operating distance and its shock on air demand.

Table 11
Impacts of HSR on domestic air transport demand (percent change).

Air transport service	No. of passengers		No. of flights		No. of flight seats	
	Fixed effect	Random effect	Fixed effect	Random effect	Fixed effect	Random effect
All city-pairs	− 28.2	− 28.0	− 24.6	− 24.2	− 27.9	− 27.9
Hub city-pair	− 33.0	− 32.3	− 28.8	− 27.7	− 31.8	− 30.7
Non-hub city-pair	− 22.4	− 24.4	− 13.5	− 14.5	− 16.0	− 17.8
Distance ≤ 500 km	− 18.0	− 20.9	− 12.9	− 12.7	− 17.6	− 19.1
Distance 500 km–800km	− 34.0	− 35.7	− 24.4	− 25.8	− 27.0	− 28.8
Distance > 800 km	− 24.1	− 22.4	− 24.8	− 23.2	− 29.2	− 27.7
Beijing-Shanghai PDL	− 33.6	− 35.3	− 22.4	− 24.3	− 50.7	− 52.0
Beijing-Shenzhen PDL	− 36.0	− 31.4	− 27.9	− 22.8	− 28.1	− 24.0
Wuhan-Guangzhou PDL[a]	− 45.0	− 44.7	− 37.0	− 35.2	− 37.2	− 35.3
Aggregate two PDLs	− 38.6	− 36.7	− 29.5	− 27.8	− 37.2	− 35.0

[a] This is a section of the Beijing-Shenzhen PDL. It was opened in service on December 26 2009, which is almost two years earlier than the formal operation of the entire service between Beijing and Shenzhen.

Hansen (2008). However, the analysis did find impacts are relatively larger than those found in early studies, which may reflect the fact that the Chinese HSR is in fact playing a significant role in transforming the nation's inter-city travel market. One should also note that as more people begin to travel by HSR, and as the network continues to grow, its impacts on domestic air transportation are expected to be even more substantial.

Two implications can be drawn from the research findings. First, given that HSR is the most competitive mode for the medium-distance intercity travel that connects major cities that have a hub function within a distance of 500–800 km, future planning and development of HSR should give preference to those corridors that meet such conditions to maximize the utilization and return on investment to the rail system. Second, given that HSR is likely to play a dominant role on the medium-distance travel market whereas air may still be a major player in the long-distance market in China, future planning should recognize that creating seamless connections between rail and air will make an important contribution to an economically sustainable and effective transportation system in China.

One should note that the study also has a few limitations which need to be addressed in future research. One caveat is that some controlling effects, such as the level of market competition and the effect of low cost airline services, are not captured in this study due to data limitations. Future research could improve the analytical model once such data becomes available. In addition, given that HSR development in China is a dynamic and undergoing process, future research should also focus on justifying the evolution of the impacts of HSR on other transportation modes once the national HSR system is fully completed.

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