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The implications of high-speed railways on air passenger flows in China

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\section*{A R T I C L E   I N F O}

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\section*{A B S T R A C T}

The High-speed Railway (HSR) network in China is the largest in the world, competing intensively with airlines for inter-city travel. Panel data from 2007 to 2013 for 138 routes with HSR-air competition were used to identify the ex-post impacts of the entry of HSR services, the duration of operating HSR services since entry, and the specific impacts of HSR transportation variables such as travel time, frequency, and ticket fares on air passenger flows in China. The findings show that the entry of new HSR services in general leads to a 27\% reduction in air travel demand. After two years of operating HSR services, however, the negative impact of HSR services on air passenger flows tends to further increase. The variations of the frequency in the temporal dimension and the travel time in the spatial dimension significantly affect air passenger flows. Neither in the temporal nor spatial dimensions are HSR fares strongly related to air passenger flows in China, due to the government regulation of HSR ticket prices during the period of analysis. The impacts of different transportation variables found in this paper are valuable to consider by operational HSR companies in terms of scheduling and planning of new routes to increase their competitiveness relative to airlines.

\section*{1. Introduction}

Efficiently operated High-speed railways (HSRs) offer advantages in punctual departure/arrival time, comfortable travel experience, and less CO2 emission in comparison to air travel (Givoni, 2007; Hall, 2009). The first HSR corridor was inaugurated in Japan in 1964. Then the first European HSR, TGV Sud-Est, between Paris and Lyon was opened in 1981 in France. Thereafter, many HSR lines have been constructed in other Western European countries, including ICE in Germany and AGV in Spain (Givoni, 2006). Although inaugurated in a later stage, Chinese HSR networks have expanded at an exponential growth rate because of a substantial financial support from the central government. Especially after 2008, a 4 trillion RMB stimulus package to mitigate the impact of the global financial crisis has more than doubled the investment capital for HSR construction (Amos, Bullock, & Sondhi, 2010). From the end of 2003, when the first HSR between Shenyang and Qinhuangdao was opened, until 2015, the Chinese HSR networks increased to 19,000 km, accounting for more than 60\% of global HSR networks. Chinese HSR networks were constructed in only 12 years, and on a scale larger than in the rest of the world. Regarding the fast development of HSR networks in China, a large volume of literature has reported the impacts of HSR services on local and regional economy (Chen & Haynes, 2017; Ke, Chen, Hong, & Hsiao, 2017), urban specialization pattern (Lin, 2016) and urban service industry agglomeration (Shuai, Tian, & Yang, 2017). However, the focus on the interaction between HSR and air travel is still limited in the context of China.

Different from the European HSR networks, which were developed in a relative mature aviation market with modest growth rates, the development of Chinese HSR networks parallels a fast-growing and partially deregulated aviation market (Wang et al., 2016). After two decades of air deregulation in China, China's air transportation has experienced rapid growth, especially from the start of the economic reform in 1980s due to the rapid increase in air travel demand (Wang et al., 2016). Between 1997 and 2015, domestic air passenger traffic in China grew from 5.6 million passengers to 436 million. The annual airline growth rate was almost 10\%, particularly after 2000. However, the annual growth rate of air travel is prone to be affected by unexpected social events, such as the 2003 outbreak of Severe Acute Respiratory Syndrome (SARS) and the 2008 financial crisis. In addition, after HSR operations started, first the D train services with an average operational speed 200 km/h in 2007 and then G train services with an average operational speed of 300 km/h in 2009, the airline's annual
growth began to drop progressively to reach stable growth after 2012 when there were remaining regulation, limited investment, and poor overall national policy on the aviation industry. Fig. 1 shows that China’s aviation market has been in a stage of fast growth in parallel to the expansion of HSR networks. While the volume of both air and HSR traffic increased between 2010 and 2015, HSR did so at a higher growth rate. This reflects the potential competition that HSR services offer for passenger transportation in China. Apart from unexpected socio-economic events, the operation of HSR services has absorbed the demand growth for airline travel to a certain extent. In addition, HSR network expansion triggered loosening of regulations on airlines by the Civil Aviation Administration of China (CAAC), such as partially flexible air fares and more operator licenses for private and low cost airline companies (Zhang, Yang, Wang, & Zhang, 2014).

Ex-ante studies of HSR and aviation demand have been conducted intensively, primarily predicting the intermodal market share and focusing on a handful of major corridors where HSR development has occurred (Gonzalez-Savignat, 2004; Mao, 2010; Park & Ha, 2006; Román, Espino, & Martin, 2007). In contrast, very often a lot of ex-post studies such as reports, white papers conducted or commissioned by transportation companies are unavailable to the public due to due to the confidentiality of the operational data from the transportation companies (Dobruszkes, Dehon, & Givoni, 2014; Li & Loo, 2016). Ex-post research is further relatively limited in academia, especially in China with a strong governmental control on the railway and aviation industry and the application of relevant HSR geo-economic and transportation variables is rather crude in the data and model application.

This paper aims to fill this gap by conducting an ex-post study on the impact of HSR on air travel demand in the context of China using balanced and unbalanced panel data analysis. Firstly, using a balanced panel data set collected for 270 cross-sections over seven years, we examine the relationship between HSR services and air passenger demand using variance component models. The analysis takes into account city pairs with and without HSR-air competition over the period 2007–2013 to understand the impact of geo-economic HSR variables (such as HSR entry and duration of operating HSR services) on air travel demand. Secondly, we employ within-between models (Bell & Jones, 2015; Nieuwenhuis, Hooimeijer, van Ham, & Meeus, 2016), using an unbalanced dataset containing only 138 city pairs with HSR-air competition from 2007 to 2013, to specify how HSR transportation variables are specifically interacted with the air travel demand in the two geographic (temporal and spatial) dimensions. We do so because the transportation variables, such as frequency, travel time, and fare, vary both in terms of the duration of operation of the HSR services (temporal dimension) and between different HSR routes (spatial dimension). Previous research has focused mainly on one of the dimensions.

In the next section, we present a literature review on the competition between HSR and air transportation. Following this is the research design, which discusses the variables used and data collection, as well as methodologies for the panel data analysis. The subsequent sections present the empirical results of the balanced and unbalanced panel data analysis. Finally, we discuss our main findings and their policy implications.

2. Literature review

Although there is cooperation between airlines and HSRs by means of feeding passengers from HSR spokes to hub airports (if booking systems between airlines and HSR companies have been coordinated) (Givoni & Banister, 2006), HSR has substantial competitive effects on air transportation, especially on point-to-point city pair markets. Research has confirmed that after the opening of new HSR services, the HSR will have substitution effects on air travel by means of diverting original air passenger flows into the HSR. The first study is from Janić (1993), who claimed that HSR transportation in Europe competes with air transportation over a relatively large range of distances, between 400 and 2000 km. A broad range of ex-ante academic literature then emerged, focusing on the impacts of HSR on predicted demand for airline travel in different contexts. In France, Haynes (1997) found that after a few years of HSR operation, air traffic dropped by 50% between Paris and Lyon. In Spain, González-Savignat (2004), based on a stated preference experimental design, predicted the HSR’s impacts on the reduced market share of airlines (50%) between Madrid and Barcelona. In Korea, Park and Ha (2006), relying on the stated preference model calibration, examined the effects of HSR on domestic air transportation demand in Korea and estimated a demand reduction between 34% and 75% between Seoul and Daegu. In Germany, to describe the consumer selection behavior between HSR and airlines, Ivaldi and Vibes (2005) used a theoretical simulation model to analyze the intermodal competition in the Cologne-Berlin route, finding that the entry of HSR reduces the fares and the airline flight frequency.

With the fast development of HSR, especially in China and Europe, a few ex-post studies of HSR impacts on air travel have been carried out. The advantage of ex-post research is the accuracy of reflecting the actual effect of intermodal competition rather than the relatively poor performance of prediction embedded in ex-ante research (Givoni & Dobruszkes, 2013). Dobruszkes (2011) and Fu, Zhang, and Lei (2012) used aggregated data and observed impacts of HSR-air competition in Europe and China, but did not implement econometric analysis on a large set of routes. That type of observed ex-post research has raised the issues of the unclear causal relationship of HSR-relevant factors and the lack of representativeness. Recently, studies have used econometric analysis to overcome this deficiency by focusing on the cases of Europe and China (Albalate, Bel, & Fageda, 2015; Chen, 2017; Fu, Lei, Wang, & Yan, 2015). However, the indicators for the HSR are dummy variables. These are unable to accurately reflect the influence of HSR related to geographic transportation factors such as travel time, frequency, and ticket fare. Other researchers have used transportation variables of HSR such as travel time, the frequency of trains (Clewlow, Sussman, & Balakrishnan, 2014; Dobruszkes et al., 2014; Zhang, Yang, & Wang, 2017) and the length of railway networks (Li & Loo, 2016) to specify the influence of HSR on airlines using either time series (temporal dimension) or cross-section (spatial dimension) analysis.

Our review of the literature shows that studies regarding the competition between HSR and airlines are largely based on a European context and interpret the transportation variables of HSR only in either the “temporal” or the “spatial” dimension. This means that the variations in transportation variables in the other geographic dimension are not taken into account simultaneously (Table 1). Hence, our first hypothesis is that the influence of the transportation variables varying in the temporal dimension differs from those varying in the spatial dimension. Our panel data set allows for including both dimensions in the analysis. Second, we hypothesize that the entry of HSR services with respect to the growth rate of air travel demand may not be as significant as in Europe until a certain year of operating HSR services. The fast economic growth in Chinese cities and the increasing purchasing power of urban citizens have resulted in a fast-growing potential market for both air travel and HSR travel in China. Although some air passengers
divert to HSR, there still exists a high demand for air travel even after opening new HSR services.

3. Research design

3.1. Overview of variables and data

The analysis is at the city-pair level where the competition between HSR and air is taking place for intercity city travel in China. Data are combined for each city for those cities with multiple airports and/or HSR stations. China has two types of high-speed trains (HST) for intercity city travel that compete with airlines: the G train with an average operational speed of 300 km/h since 2009 and the D train with an average operational speed 200 km/h since 2007. Data are compiled in December of each year and contain all existing city pairs with HSR-air competition each year from 2007 to 2013. By the end of 2013, there were 144 city pairs with HSR-air intermodal competition and 39 cities in total (Fig. 2) in our dataset. Table 2 lists the variables and gives the descriptive results of dependent and independent variables.

In this research, our main focus is the annual air travel passengers. This variable includes annual origin-destination passengers traveling between a pair of cities, which reflects the demand side of the aviation market. It should be noticed that our air data sets from CAAC are actual airline passenger flights between HSR and airlines in China, in addition to the dummy variable of the entry of HSR services, the duration of operating HSR services and air passenger travel may be non-linear. Hence, we included a quadratic term of duration in the model.

With regard to geo-economic variables, the primary explanatory variables of most econometric demand models of air transportation are typically socio-demographic variables, such as gross domestic product (GDP) per capita and population size (Clewlow et al., 2014). We tested the sum of multiplied GDP per capita and population for the two ends of each city pair, respectively. The multiplied formats of those socio-economic variables yield the greatest explanatory power when according to the travel distance and potential travel demand. We use the natural logarithm transformation on the dependent and independent variables.1

HSR Transportation Variable | Temporal Dimension | Spatial Dimension
---|---|---
Frequency | HSR companies can adjust the frequency of HSR trains within a city pair over time and according to the extension of HSR networks. | City pairs have different frequencies of HSR train service according to the travel distance and potential travel demand.
Ticket fare | HSR companies can adjust the fare for a city pair over time | City pairs have different fares according to the travel distances, seat classes, and potential travel demand.
Travel time | The travel time can change with the technology breakthrough such as development of engines, carriages, transmission. In a short duration of operating HSR services, travel time is relatively stable regarding the fixed travel distance. | City pairs have different travel times according to their travel distances and intermediate stops.

3.2. Methodology

Bresuich-Pagan tests indicate that ordinary least squares (OLS) are inefficient due to heteroskedasticity and therefore, we have used three variance components models for the analysis. The first one is used for the balanced panel data analysis, the second for the unbalanced panel data analysis and the third for subgroups of unbalanced panel data according to flight distance.

The first model is a balanced panel data set taking into account 138 city pairs2 still with HSR-air intermodal competition after the entry of HSR services and 132 city pairs without the entry of HSR services between 2007 and 2013.3 Our initial set of independent variables is a mix of geo-economic and general HSR variables as well as air transportation variables introduced in model 1 in Table 1. The aim of this balanced

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1 The existing HSR routes without air competition and newly planned ones are not shown in the map.

2 The city pairs (Chengdu-Chongqing, Fuzhou-Xiamen, Wenzhou-Fuzhou, Jinan-Nanjing, Hangzhou-Hefei, Shijiazhuang-Zhengzhou) directly abandoned by the airlines rather than the absolute value of air passenger growth. We use the natural logarithm transformation on the dependent and independent variables to reflect the elasticity relationships. It should be noticed that regarding the causality between the HSR travel and air travel, by controlling other major influencing factors of air passenger numbers, the analysis in this paper focuses on association rather than direct causality (Li & Loo, 2016).

3 The 132 city pairs with the entry of HSR services in 2014 were used as counterfactual scenarios.
model is to isolate the general impacts of the entry of HSR services and the influence of the duration of operating HSR services after HSR entry on the overall air passengers in China without taking into account specific transportation variables of HSR, such as travel time, frequency and ticket fare. The first balanced panel data model is formulated as follows:

$$Y_{it} = x_{it} \beta + z_i \delta + u_i + \varphi_{it}$$

where $i$ and $t$ represent entity $i$ and year $t$, respectively. $Y_{it}$ is the dependent variable, being the number of air passengers on city pair $i$ in year $t$. $X_{it}$ and $\beta$ denote the vector of independent time-variant variables and corresponding coefficients. $Z_i$ and $\delta$ denote the vector of independent time-invariant variables and corresponding coefficients. $U_i$ is the specific intercept for each entity and represents all unobservable time-invariant characteristics of entity $i$ that influence the dependent variable. $\varphi_{it}$ is the random error term. The coefficients for the time-invariant variables will be omitted within the fixed effect (FE) estimator.

With the second model, we analyze impacts of variations in specific HSR transportation variables on air passengers from the temporal and spatial dimensions, rather than estimate the impact of the entry of HSR services on overall air passengers. In this analysis, we replace the two...
| Indicator                      | Explanation                                                                 | Source                                                                 | Source Details                                                                 | Models | Mean       | Standard Deviation |
|-------------------------------|-----------------------------------------------------------------------------|----------------------------------------------------------------------|---------------------------------------------------------------------------------|--------|------------|---------------------|
| **Dependent variable**        |                                                                             |                                                                      |                                                                                | M1    | M2        | M3                  |
| Airflow (passengers)          | Domestic O/D airline passengers traveling between a city pair. From 2007 to 2013 for 144 city pairs | From CAAC (Civil Aviation Administration of China)                    | x x x                                                                          | 521436.4 | 775618.4 |                      |
| GDP per capita (yuan)         | Combined per capita gross domestic product of each city pair of origin and destination | Chinese urban statistical yearbooks from 2008 to 2014                  | x x x                                                                          | 3.67E+09 | 4.64E+09 |                      |
| Pop (10,000 inhabitants)      | Combined population of each city pair of origin and destination             | Chinese urban statistical yearbooks from 2008 to 2014                  | x x x                                                                          | 779045.4 | 716438.9 |                      |
| Duration (year)               | Duration of operating HSR services of each city pair                        | Compiled from the operational company websites and opening public resources | x x x                                                                          | 1.856 | 1.802 |                      |
| HSR dummy                     | Dummy variable that takes a value of 1 for the presence of HSR services (either G train or D train) those routes on which HSR services compete with airline flights |                                                                      | x                                                                              | 0.452 | 0.498 |                      |
| Year dummies                  | Dummy variable that takes the year 2007 as the reference                    |                                                                      | x x x                                                                          | 2010 | 2.009993 |                      |
| **Transport variables of HSR**|                                                                             |                                                                      |                                                                                |        |            |                     |
| Gfreq                         | Daily G trains traveling between a city pair from 2007 to 2013              | Time schedule software: Jipin http://www.jpskb.com/                    | x x x                                                                          | 4.826 | 21.016 |                     |
| Dfreq                         | Daily D trains traveling between a city pair from 200 to 2013               | Time schedule software: Jipin http://www.jpskb.com/                    | x                                                                              | 4.918 | 12       |                     |
| Totfreq                       | Total frequency number of G and D trains traveling between a city pair       | http://www.jpskb.com/                                                | x                                                                              | 9.744 | 27.016 |                     |
| Gfare (yuan)                  | Second-class ticket fare of G trains between a city pair from 2007 to 2013  | Time schedule software: Jipin http://www.jpskb.com/                    | x                                                                              | 378.565 | 163.456 |                     |
| Dfare (yuan)                  | Second-class ticket fare of D trains between a city pair from 2007 to 2013  |                                                                                    | x                                                                              | 298.437 | 105.296 |                     |
| Gtime (minutes)               | The shortest travel time of G trains between a city pair from 2007 to 2013  |                                                                                    | x                                                                              | 273.233 | 118.083 |                     |
| Dtime (minutes)               | The shortest travel time of D trains between a city pair from 2007 to 2013   |                                                                                    | x                                                                              | 389.678 | 188.384 |                     |
| AverageHSRFare               | Weighted ticket fare according to frequency numbers and ticket fares of G and D trains | Using the GIS model in 2015.9                                              | x                                                                               | 281.869 | 142.575 |                     |
| AverageHSRTime (minutes)      | Weighted travel time according to frequency numbers and travel times of G and D trains | Using the GIS model in 2015.9                                              | x                                                                               | 370.597 | 183.534 |                     |
| StationTime (minutes)         | Summed transportation time by car from the administrative center of origin cities to departure stations and from arrival stations to the administrative center of destination cities | Using the GIS model in 2015.9                                              | x                                                                               | 40.087 | 8.744 |                     |
| **Transportation variables of airlines** |                                                                             |                                                                      |                                                                                | M1    | M2        | M3                  |
| AirFare                       | Annual domestic airline ticket fare for 144 city pairs in China from 2007 to 2013 | From the domestic data of Chinese airlines from 2007.12 to 2013.12   | x x x                                                                          | 68622.81 | 30995.4 |                      |
| FlightTime (minutes)          | Point-to-point flight time for each city pair                               | From CAAC Civil Aviation Administration of China                        | x x x                                                                          | 111.410 | 28.5522 |                      |
| AirportTime (minutes)         | Summed travel time by car from the administrative center of origin cities to departure airports and from arrival airports to the administrative center of destination cities | Using the GIS model in 2015.9                                              | x x x                                                                          | 69.882 | 14.816 |                      |

* One might argue that air fare is endogenous because of reverse causality between air flow and air fare. However, here air fare is a proxy calculated by flight distance times fare index. There are three types of air travel fare index: long-haul flight > 1500 km, medium-haul flight 800–1500 km, short-haul flight < 800 km, and annual air passenger flow is less than 50,000. Thus, air fare is an indicator much related to flight distance instead of unexplained market power which causes endogeneity. Thus, we do not expect an endogeneity bias on air fare.
general HSR variables with the specific HSR transportation variables i.e. travel time, frequency and ticket fare. For this panel data set, only the city pairs where direct HSR services still compete with air services between 2007 and 2013 are considered. Provided by the characteristics of unbalanced panel data and two geographic variations in HSR transportation variables, we employ a hybrid random effects model, also called a between-within (BW) model, to interpret the results in two geographic dimensions (Bell & Jones, 2015; Bell, Fairbrother, & Jones, 2016, pp. 1–38). The BW model is called a hybrid model because it combines the advantages of both fixed and random effects models and has been implemented in the panel data studies (Bell, Johnston, & Jones, 2015; Nieuwenhuis et al., 2016) to separate the variations of independent variables into two levels. It can be written as:

\[ Y_i = \beta_0 + \beta_1 x_{it} + \beta_2 z_i + \epsilon_i \]  

where \( \beta_1 \) is the within effect and \( \beta_2 \) is the between effect of a series of time-variant variables \( x_{it} \) (Bell & Jones, 2015). Rather than assuming heterogeneity away with the FE, the BW method estimates how the effects of within and between city pair variations in independent variables vary over time and space on the dependent variable. Any time-invariant characteristics (both observed and unobserved) are automatically controlled for, as the sum of their change will always be zero. Therefore, the estimations for time-varying variables in BW models are identical to the estimations in FE models. Additionally, a BW model includes random effects and allows for the inclusion of time-invariant variables \( \beta_2 \), providing additional information on differences between city pairs that could not be estimated using a fixed effects model (for a more detailed description of the method, see Bell & Jones, 2015).

The third model is an extension of the BW model by distinguishing between various distance categories. In Fig. 3, it is found that in the travel distance less than 600 km, the number of traveling HSR passengers is much larger than that of air passengers and the market share is dominant by HSR travel, whereas in the distance longer than 1100 km, the number of traveling HSR passengers is much larger than that of air passengers and the market share is dominant by air travel. Therefore, we aim to delve into how the elasticity of temporal and spatial transportation variables varies over time and space on the dependent variable. Any time-invariant characteristics (both observed and unobserved) are automatically controlled for, as the sum of their change will always be zero. Therefore, the estimations for time-varying variables in BW models are identical to the estimations in FE models.

4. Panel data regression results

4.1. General effects of HSR on air passengers

Table 3 shows the results for the balanced panel model. After the Hausman test, we reject the null hypothesis at the p = 0.05 significance level that the coefficients estimated by the efficient random effects model are the same as the coefficients of the FE model; thus, the FE model is more appropriate here for the analysis. From the FE model, the presence of HSR services has a negative relationship with the air passenger flows. The entry of HSR services will lead to a 27% (100 * (EXP (−0.3284) − 1)) decrease in the air travel passengers. Furthermore, the duration of operating HSR services since the moment of HSR entry reflects a lag effect of HSR services on airline passenger flows. The negative coefficients of the duration variables are significant except for the duration variable of one year’s operation of HSR services, which means that after two years’ operation of HSR services, the airline passenger flows start to decrease more due to the substitution effect from HSR. This is because at the initial stage of HSR development, HSR networks had not yet been formed and travelers’ awareness of the HSR alternative was not so high that the substitution between HSR and air was still limited. However, with the gradual and fast extension of HSR networks in China, its substitution effect on air travel demand has been increasing. Moreover, the long-term impact of operating HSR services on air travel is not linear, especially after 6 year’s operation of HSR services there is an inverted growth trend compared to the previous years. This indicates that in the long run, the air companies try to adapt

Table 3

| Fixed Effects | Random Effects |
|--------------|---------------|
| lnAirflow    | lnAirflow     |
| HSRdummy     | −0.232*       | −0.171 |
| Duration = 1 year | −0.275       | −0.326 |
| Duration = 2 year | −0.430*       | −0.229 |
| Duration = 3 year | −1.359***     | −1.123*** |
| Duration = 4 year | −1.101**      | −0.759** |
| Duration = 5 year | −2.276***     | −1.813*** |
| Duration = 6 year | −1.861***     | −1.300*** |
| LnGDP        | −0.118        | 0.888*** |
| LnPop        | 0.314         | 0.737*** |
| LnAirFare    | −3.168**      | −0.666 |
| FlightTime   | 0.000         | 0.013 |
| Dummy2008    | −1.7563**     | −0.391 |
| Dummy2009    | −0.774**      | −0.142 |
| Dummy2010    | 0.712**       | 0.716*** |
| Dummy2011    | 1.126***      | 0.731*** |
| Dummy2012    | 1.514***      | 0.582** |
| Dummy2013    | 2.026***      | −0.027 |
| Constant     | 45.200**      | −9.802 |
| Observations | 1890          | 1890 |
| R2 within    | 0.136         | 0.126 |
| R2 between   | 0.037         | 0.180 |
| R2 overall   | 0.000         | 0.157 |

Standard errors in parentheses * p < .1, ** p < 0.05, *** p < 0.01.

Fig. 3. Actual volume of passenger flows carried by airlines/HSR in 2013 vs distance of city pairs.
their operational strategy to weaken the competitive pressure from the HSR.

As to the control variables, although the coefficient of population is not statistically significant, the sign of this coefficient is as we expected. In addition, the coefficient associated with the GDP variable is negative though not statistically significant. This finding is the same as in some other European research, such as Albalate and Fageda (2015) and Dobruszkes et al. (2014), in which the coefficient of GDP per capita is negative and not significant. Moreover, an increase in air fare is negatively related to the number of air passenger flows, as expected. This reasonably suggests that in the Chinese aviation market from 2007 to 2013, if airline companies increased the airline fare, people were less willing to travel. Furthermore, as expected, the year dummy variables 2008 and 2009 have a negative relationship with the number of air passenger flows due to the Asian financial crisis in 2008. The positive coefficients of dummies from 2010 to 2013 are explained by the recovering economy and aviation industry after the global financial crisis.

In sum, the opening of HSR services initially has minor influence on the number of air passenger flows in China compared to Europe (Albalate et al., 2015). However, with 2 years' operation after the entry of HSR services, the negative impacts of operating HSR services starts to increase.

### 4.2. Specific effects of HSR transportation variables on air travel passengers in the temporal and spatial dimensions

Table 4 shows the results of unbalanced panel data analysis, focusing on only city pairs with HSR services between 2007 and 2013. Given that there may exist autocorrelation and heteroscedasticity issues, we still include the year dummy variables by controlling for any changes over time and cluster the standard errors with each city pair, which could account for serial correlation and heteroskedasticity. The

| Table 4 | Unbalanced panel model. |
|-----------------|-------------------------|
| **Temporal dimension (within a city pair)** |  |
| Ln(Frequency) $^a$ | $-0.515^{**}$ |
| Ln(HSR fare) $^b$ | $0.658$ |
| Ln(HSR travel time) $^c$ | $-1.125$ |
| Ln(GDP per capita) | $-0.988$ |
| Ln(Population) | $5.560^{**}$ |
| Ln(Airfare) | $2.056$ |
| **Spatial dimension (between city pairs)** |  |
| Ln(Frequency) $^a$ | $0.686^{**}$ |
| Ln(HSR fare) $^b$ | $0.171$ |
| Ln(HSR travel time) $^c$ | $3.047^{***}$ |
| Ln(GDP per capita) | $1.249^{***}$ |
| Ln(Population) | $0.948^{***}$ |
| Ln(Airfare) | $-2.195^{*}$ |
| Ln (Access/egress time to/from stations) | $-0.231$ |
| Ln (Access/egress time to/from airports) | $0.426$ |
| Ln (Flight time) | $2.748^{**}$ |
| Dummy2008 | $1.105$ |
| Dummy2009 | $0.820$ |
| Dummy2010 | $1.152$ |
| Dummy2011 | $1.224$ |
| Dummy2012 | $1.031$ |
| Dummy2013 | $1.441$ |
| Constant | $-38.980^{***}$ |
| $N$ | $426$ |
| R2 within | $0.09$ |
| R2 between | $0.356$ |
| R2 overall | $0.312$ |

$^a p < .1$, $^b p < 0.05$, $^c p < 0.01$.  
$^a$ The frequency of general HSR services is the weighted average number of G and D trains.  
$^b$ The ticket fare of general HSR services is the weighted average number of G and D trains.  
$^c$ The travel time of general HSR services is the weighted average number of G and D trains.

Based on the results of within effects, we observe that a 10% increase in the frequency of HSR services within a city pair leads to a 5.2% reduction in air travel passengers. The coefficients of ticket fare and travel time are not significant. This is reasonable because the ticket fare and travel time of HSR services in the temporal dimension for a city pair hardly vary after the start of HSR services. The National Development and Reform Commission (NDRC) instead of the China Railway Corporation (CRC) has the authority to decide the ticket fare for each city pair regarding travel distance. To increase the use of HSRS, the NDRC did not allow the CRC to adjust the HSR ticket fare according to market mechanisms before 2016. Therefore, the ticket fare of HSR services for a city pair after a few years of operation is almost the same as the one at the beginning stage of operation. In addition, with the duration of operating HSR services increasing, similar to the case of ticket fares, the travel time in the temporal dimension cannot be reduced to a large extent without new technology breakthroughs on the operational speed of HSR services. Note that a national speed reduction of HSR services occurred after the accident involving a D train crash in 2011 when the government decided to reduce the operational speeds of both D and G trains. Even though the travel speed of G trains decreased from 350 to 300 km/h and that of D trains from 250 to 200 km/h, the influence of travel time in the temporal dimension is still rather limited.

With regard to the control variables, a 10% increase in population will respond with an 55% increase in air passenger flows, which is remarkable compared to European countries (Clewlow et al., 2014). This is reasonable because with the fast urbanisation process in the last ten years in China, more and more people have migrated from rural areas into urban areas, which leads to a potential market for the induced air passengers; furthermore, the cities connected by HSR and air are also the major nodes in China with fast-growing diverted air passengers from other low-speed transportation modes. The coefficient of the ticket fare of airlines is not significant anymore in this model compared to the previous balanced panel model, which means that facing competition from HSR, the strategy of lowering air ticket fare in the long run will not contribute to the improved competitiveness of airlines.

Furthermore, from the results of between effects, most importantly, a 10% increase in the travel time of HSR services between city pairs will lead to a 30% increase in air passenger flows. Our research confirms that variations of travel time between city pairs in the spatial dimension, instead of variations of travel time within a city pair in the temporal dimension, are important to explain differences in air passenger flows between city pairs. This means that regarding a specific travel speed of HST decreasing the travel time by limiting the intermediate stops between city pairs will be efficient to reduce air travel passengers. Interestingly, a positive relationship exists between the frequency of HSR services and airline travel passengers in the spatial dimension. City pairs with a higher frequency of HSR services tend to have more airline travel passengers. It is likely that the city pairs with a larger frequency of HSR services are normally the ones with higher GDP per capita and population, which creates higher passengers for intercity travel (Dobruszkes et al., 2014). Due to the potential correlation between the frequency of HSR and socio-economic status of city pairs in the spatial dimension, rather than the variations of the frequency of HST in the spatial dimension, the variations of the frequency in the temporal dimension actually influence air travel passengers. In addition, we

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*The urbanisation level in China had grown from 26% in 1990, to 52.6% by the end of 2012 (UNDP, 2013). It is estimated that China's urbanisation level will increase to 60% in 2020 (Xin, 2014).*
observe that the coefficient of the HSR ticket fare is not significant as this effect may already have been captured by the travel time variable as a result of the fixed HSR ticket fare mechanism.

With regard to the control variables, city pairs with higher GDP per capita and population attract more air travel passengers. The coefficient of air ticket fare is still negative since city pairs with higher air fares have lower air travel passengers. The flight time of city pairs is positively related to air passenger flows. This is interesting because it indicates that the competitiveness of air travel relative to HSR travel increases with increasing distance (flight time) between origin and destination, as time savings using air transportation become larger. The coefficients of both access/egress time to/from stations and airports are not significant. This is reasonable since most HSR stations in China are located in the suburbs of cities, similar to locations of airports. Wang et al. (2016) confirm that HSR stations located on average 23.2 km away from the city center had a little shorter travel time by road transportation than airports (32.6 km). Although it is not significant in this aggregate research, the difference in the access and egress time to/from terminals likely might be significant in disaggregate research.

Overall, the growing urbanized population in cities with increasing passengers for long-distance travel contributes to the fast growth in air travel passengers in China. Among HSR transportation variables, the frequency of HSR services in the temporal dimension and the travel time of HSRs in the spatial dimension are the crucial factors for the competition between HSR and airlines in China.

4.3. The specific impact of HSR services according to travel distances

Table 5 only shows the results of variables of our main interest, namely, the frequency of general HSR services in the temporal dimension and the travel time of general HSR services in the spatial dimension. We further separate the general HSR services into D and G train services.

On short-haul city pair markets of flight distance less than 600 km, an increase of general HSR frequency in the temporal dimension has a negative impact on air passenger flows. Also, the travel time of HSR services in the spatial dimension is elastic to air passenger flows. We also find that the coefficient of the frequency of D trains is significant, whereas the coefficients of the frequency and travel time of G trains and the coefficients of the travel time of D trains are not significant. This indicates that HSR operators are better off increasing the total number of HST frequencies, especially D trains, for the city pairs with a flight distance of less than 600 km, than increasing the frequency of G trains.

On medium-haul city pair markets of distance between 600 and 1100 km, the travel time of general HSR and those of G trains in the spatial dimension are elastic to air passenger flows. The coefficient of the frequency of G trains in the temporal dimension is significantly negative to the air passenger flows. This means that on medium-haul markets, an increase in the frequency and a reduction of intermediate stops of G trains service will be more efficient than that of both G and D train services for improving the overall competitiveness of HSR services.

For long-haul travel city pair market of flight distance over 1100 km, the sample sizes of both D and G trains are not large enough for the analysis so here we only report the results of general HSR services. Neither the frequency in the temporal dimension nor the travel time in the spatial dimension is elastic to air passenger flows. Thus, we can conclude that within this travel distance, neither a reduction of travel time in the spatial dimension nor an increase in frequency in the temporal dimension will improve the competitiveness of HSR services.

5. Conclusions

This study explores the ex-post intermodal relationship between HSR and air transportation at the route level in China. By means of balanced and unbalanced panel data from 2007 until 2013, we explain HSR’s general potential to reduce air passenger flows and the relevant specific transportation variables influencing air passenger flows in two geographic dimensions: temporal and spatial.

First, by focusing on the impact of the entry of HSR services and the duration of operating HSR services on air passenger flows since entry, our research shows that after the control of the socio-economic impacts on the air travel demand, the entry of HSR services in general leads to only a 27% reduction in air travel passengers for the route with the intermodal competition between HSR and air, which is similar to the finding of (Chen, 2017; Zhang et al., 2017). This is not a significant negative impact, compared with studies such as Albate et al. (2015) in Spain, who report a more than 50% airline seat reduction after the entry of HSR services. However, after two-years’ operation of HSR services in China, the negative impact of HSR services on air passenger flows tends to increase. This reflects the typical case of China that the substitution effect of HSR networks in a fast-growing aviation market (in contrast to the more mature European market) is not significant on the growth of air passenger travel at least at the initial stage until more HSR routes have been opened and the awareness of the new service among travelers grows.

Second, our research confirms that the variations of the frequency in the temporal dimension and the travel time in the spatial dimension are significant factors in explaining air passenger flows on city pair markets where both modes compete. The frequency component in the temporal dimension indicates that HSR can improve its competitive position with respect to airlines if the HSR frequency on the route is increased. The travel time in the spatial dimension shows that HSR has a better competitive position on city pairs with a shorter HSR travel time, as on these routes airlines have a relatively limited travel time advantage. The frequency in the spatial dimension is just the approximation of the economic level of city pairs reflecting travel passengers. The impact of travel time in the temporal dimension is rather limited even though there has been a travel speed reduction for the HSR services during the period of analysis. In contrast to the findings that HSR ticket fares are elastic with the market share in Europe (Adler et al., 2010; Behrens & Pels, 2012), the ticket fares of HSR in both the temporal and spatial

| Distance | < 600 km | 600-1100 km | > 1100 km |
|----------|----------|-------------|-----------|
| Ln(Air passenger flows) | | | |
| Ln(Frequency of HST) | −1.690*** | 1.627 | −1.022* | −0.125 | −7.126*** | 0.203 | −0.237 |
| Ln(Travel time of HST) | 3.463** | −2.696 | 2.699 | 2.744*** | 6.033*** | 2.474* | 4.788 |
| N | 170 | 54 | 155 | 210 | 65 | 181 | 62 |
| R2 within | 0.218 | 0.202 | 0.227 | 0.057 | 0.413 | 0.078 | 0.402 |
| R2 between | 0.569 | 0.698 | 0.532 | 0.423 | 0.721 | 0.479 | 0.585 |
| R2 overall | 0.448 | 0.676 | 0.427 | 0.388 | 0.665 | 0.377 | 0.598 |

*p < .1, ** p < 0.05, *** p < 0.01.
dimensions are not strongly related to the air passenger flows in China, as a result of the fixed HSR ticket fare mechanism in the control of the government. Fare probably can play an important role in competition only when it fluctuates according to the market. Our research further confirms that the short stretch of HSR routes in the spatial dimension and the high frequency of HSR services in the temporal dimension can definitely increase the competitiveness of HSR relative to airlines.

While our research has identified the reaction of airlines to HSR services between 2007 and 2013, we note that from January 2016 the HSR ticket fares were no longer under the control of the NDRC (NDRC, 2015). HSR operators acquired the right to price train seats largely based on market passangers. Thus, future research could investigate how the flexible ticket fare influences the intermodal relationships between HSR and airlines in both the temporal and spatial dimensions. Second, although the aggregate time cost of intra-city trip to/from terminals are not significant in this research, future research could also study whether the individual differences of disaggregate time cost of intra-city trip to/from terminals influence the competitive relationships between HSR and airlines. Third, because long-distance transportation networks evolve over time and shape demand to some extent, it will be of interest to also take into account the recent conditions of both HSR and airline and from the perspectives of the demand side (actual O/D passenger flows) in both HSR and airline sides in the future, especially regarding the expansion of low-cost airline in China after 2013. Moreover, specific schemes of the subsidy for operational companies, air operation, airport and air traffic control, which vary from case to case, could also influence the cooperative relationship between HSR and air travel. A detailed case study research could shed light on that.

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Appendix A. Supplementary data

Supplementary data related to this article can be found at http://dx.doi.org/10.1016/j.jageo.2018.05.006.

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