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Impact of High-Speed Rail Network Development on Airport Traffic and Traffic Distribution: Evidence from China and Japan

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Abstract: We explore the impacts of high-speed rail (HSR) development on airport-level traffic by considering not only the availability of air-HSR intermodal linkage between the airport and HSR station but also the position of the airport's city in the HSR network. The latter is measured by both the degree centrality (to reflect connectivity) and the harmonic centrality (to reflect accessibility). Using a sample of 46 airports in China and a sample of 16 airports in Japan over the period of 2007-2015, we conduct regression analysis and compare the effects of HSR network development on airports in these two Northeast Asian countries. We find that as HSR connectivity or accessibility increases, there is, on average, a decline in airports' domestic and total traffic in China but little change in Japan. Meanwhile, we observe a strong complementary effect of HSR to feed international flights with the presence of air-HSR intermodal linkage. As a result, some airports may experience a total traffic increase. In China, hub airports tend to gain traffic regardless the availability of air-HSR linkage, while non-hub airports are likely to lose. In Japan, on the other hand, airports with air-HSR linkage tend to gain traffic regardless the hub status. Our analysis also reveals some differentiated impacts of HSR connectivity and accessibility in China. An important policy implication is that the investment in air-HSR intermodal linkage at busy airports may not help with realizing the benefit of congestion mitigation and emission reduction. Rather, policy makers may invest air-HSR linkage at regional airports which have the potential to be converted into international gateway hubs.

Keywords: High-speed rail; Airport traffic; Degree centrality; Harmonic centrality; Substitutability and complementarity; Air-HSR intermodal

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1. Introduction

By 2018, high-speed rails (HSR) have been operated in 16 countries and regions, achieving an extensive track length of over 40,000 kilometers (km) worldwide (International Union of Railways [UIC], 2018). Evidence of air traffic reduction on short/medium-haul routes (less than 800-1000km) facing direct competition from HSR has been well documented in the context of Northeast Asia such as China (Chen, 2017; Fu et al., 2012; Wan et al., 2016; Wang et al., 2018; Zhang et al., 2017; Zhang and Zhang, 2016), Japan (Clever and Hansen, 2008; Demizu et al, 2017; Fu et al., 2014; Kojima et al., 2017; Wan et al., 2016), and South Korea (Park and Ha, 2006), as well as in Europe (e.g. Albalate et al, 2015; Behrens and Pels, 2012; Clewlow et al, 2014; Dobruszkes, 2011; Dobruszkes et al., 2014; Jiménez and Betancor, 2012). Such substitution effect of HSR has been in fact welcomed by some policy makers for two major reasons. First, HSR may replace some flights, release airport slots, and alleviate airport capacity shortage (Jiang and Zhang, 2014) especially when it is infeasible to expand airport capacity to cope with demand surge. Second, replacing flights with HSR services may help to mitigate carbon emissions, as HSR releases much less greenhouse gas per passenger-km than air transport[1] (e.g. Eurocontrol, 2004; Givoni, 2007; Givoni and Banister, 2006; Sun et al., 2017). As a result, some European countries have been encouraging the air-HSR intermodal transport such that HSR can replace air transport to feed long-haul or international flights (Commission of the European Communities, 2001).

Despite abundant route-level studies, it is the amount of traffic reduction at an airport or in the entire air transport system that matters to airport congestion mitigation and emission reduction. First, with mixed empirical evidence on HSR's impacts on long-haul air routes, one may not rule out the possibility of an overall increase in air traffic. For example, Bilotkach et al. (2010) find significant positive impact on flight frequency after pooling a sample of short-haul and long-haul European routes together in a regression analysis. Based on a case study of five European city-pair markets, Dobruszkes (2011) found that in markets where HSR is less competitive than air in terms of travel time, air services continued growing despite the entry of HSR. Studies on domestic air transport markets in China have revealed an increase in airline seat capacity on routes over 800km (Wan et al., 2016) and an increase in passenger numbers on routes over 1000km (Zhang et al.,

[1] Europe Environment Agency (2014) reported that CO_2 emission by HSR is 14g per passenger-km but by air transport the number raises to 285g per passenger-km.

2018) after the introduction of parallel HSR services. Second, HSR may increase air traffic by expanding airports' catchment with air-HSR intermodal transport (Jiang and Zhang, 2014; Vespermann and Wald, 2011; Xia and Zhang, 2017). In theory, Avenali et al. (2018) prove that the provision of air-HSR intermodal services may substantially increase traffic in air routes fed by HSR and hence increase total traffic at hub airports if air and HSR are not close substitutes. Takebayashi (2016, 2018) models two competing gateway hub airports linked by HSR. He shows numerically that the congestion at the heavily congested airport may not be reduced if HSR and the congested airport collaborates (Takebayashi, 2016). Moreover, under some conditions, even reducing airport charges at the less congested airport may not attract passengers away from the congested airport via air-HSR intermodal transport (Takebayashi, 2018). Third, facing with HSR competition, airlines may be forced to develop new routes with little HSR threat, e.g. international routes. In capacity constrained airports, released runway capacity are very likely taken by longer-haul flights, leading to more rather than less emission (Givoni and Dobruszkes, 2013). As a reaction to the expansion of HSR operations, China Southern Airlines, one of the "Big Three" Chinese airlines, planned to increase the share of international routes in its network from 18.5% to 40% (CAPA, 2011). As predicted by Jiang and Zhang (2016), airlines may give priority to hubbing and increase international coverage at their hub airports.

Therefore, empirical studies on HSR's impact at the airport level are essential, but to our knowledge, very little attention has been devoted to this and we only find three related studies. Clewlow et al. (2014) study the association between the presence of HSR and airport-level domestic, intra-EU, and total traffic in Europe. Castillo-Manzano et al. (2015) estimate the impact of Spain's HSR network expansion on the number of domestic passengers at Madrid-Barajas airport. Zhang et al. (2018) quantify the "complementary" effect of HSR on airports' passenger enplanement in East Asia and Central Europe. This "complementary" effect is captured by introducing a policy variable, air-HSR integration, which is defined as the availability of on-site HSR services at the airport. All of these three studies use simple measures of HSR operations, such as a dummy variable indicating the existence of HSR service (Clewlow et al., 2014), the number of HSR passengers in the railway system (Castillo-Manzano et al., 2015) and a dummy variable indicating the practice of air-HSR integration (Zhang et al., 2018). These approaches ignore airports' heterogeneous positions in an HSR network. In particular, airports located at the margin of the HSR network might face much weaker HSR impacts than those located at the center of HSR network. This is because in the latter case either a larger share of airport traffic is facing direct competition from HSR or a larger number of passengers can be fed into the airports by air-HSR intermodal transport. Thus, it is essential to measure individual airport city's capability to reach other cities via the HSR system.

This study contributes to the existing literature by investigating the impact of HSR development on airport-level traffic in a more comprehensive way.[2] That is, we consider not only the airport-HSR station linkage but also the position of the airport in the entire HSR network, together with airport hub status. This allows us to achieve the followings. First, we are the first to take a network view of HSR development by associating air transport with the city's connectivity and accessibility to other cities in the HSR network. Second, we capture not only airport traffic increase due to HSR's feeding, but also traffic reduction due to HSR network development. Third, unlike Zhang et al. (2018) who examined the different impacts of air-HSR integration alone on hub and non-hub airports, we compare the joint impacts of HSR network development and air-HSR linkage on hub and non-hub airports. Fourth, we not only study total passenger traffic, but also investigate the impacts on domestic and international traffic separately. Another major contribution of our study is to compare the effects of HSR in China and Japan. This provides a better understanding on how different development stages of HSR could influence the results, which might provide important insights for future HSR development and airport capacity planning.

In terms of methodology, we fit econometric models with two sets of annual data over the period of 2007-2015. One consists of 46 airports in China and the other consists of 16 airports in Japan. A series of regression analysis is conducted to establish the relationship between domestic, international and total airport traffic and abovementioned factors. We apply two concepts widely used in the complex network theory, degree centrality and harmonic centrality, to measure an airport city's position in the HSR network. Degree centrality is used to measure an airport city's connectivity to other cities via HSR services, while harmonic centrality is used to measure an airport city's proximity, or so-called accessibility as defined by Wang et al. (2011), to all the other cities in the HSR network via HSR services.

Our findings reveal that a good connection between the airport and HSR station may bring an extra positive impact on airport traffic in spite of the traffic reduction associated with improved

[2] This study deals with airport-level traffic, but it can be extended to investigate traffic impact at the more aggregated level for issues such as carbon emissions.

HSR connectivity and accessibility. This moderation effect mainly comes from the increase in international traffic. As a result, a net increase in airport passenger traffic may occur. Such net traffic increase is more likely to be achieved by adding HSR connections than by improving proximity to other cities in the HSR network, and is more likely to occur at hub airports than at non-hub airports.

The rest of this paper is organized as follows. Section 2 briefly compares China and Japan's HSR development and network structures, defines two measures of an airport city's position in an HSR network by applying the concepts of degree centrality and harmonic centrality, and then develops the econometric specifications for regression analysis. Section 3 describes the data used in the research and the construction of variables. Regression results and main research findings are reported in Section 4. Section 5 provides concluding remarks and policy implications.

2. Methodology

2.1 HSR development in China and Japan

In this paper, we conduct a comparative study about the impact of HSR on airport traffic in China and Japan. We select these two countries for three major reasons. First, these two countries account for nearly 80% of the world's total HSR traffic in terms of passenger-kilometers.[3]

Second, China and Japan are underlying very different stages of HSR development. Figure 1 and 2 show the development of HSR network in China and Japan respectively during our sampling period (2007-2015) as well as the locations of our sampled airports. In China, even though the construction of the first HSR line was completed in 2003,[4] the HSR service was not provided until 2007 when the government implemented its sixth railway speed up campaign. However, over the sampling period, China's HSR network has grown out of almost nothing and expanded into the largest HSR system in the world, achieving a total length of 19730 km, encompassing 27 out of 31 provinces (Figure 1). Japan, on the other hand, inaugurated its first HSR (Shinkansen) service connecting Tokyo and Osaka in October 1964, just in time for the Tokyo Olympics, shaving 2.5 hours off the 513 km journey. After that, due to the public's

[3] Calculated by the authors based on HSR traffic data from International Union of Railways.

[4] Qinhuangdao-Shenyang passenger-dedicated line between Qinhuangdao and Shenyang is the first newly built HSR in China. The construction of this line started on August 1999 and finished on October 2003.

affirmative response to these fast train services, the Shinkansen system experienced an impressive expansion between 1970s and 1990s. The main structure of Japan's network was established in 1990s and since then there was little change until 2004. Recent expansion projects since 2010 are relatively minor, since they only involve three branch lines linking to the peripheral regions (Figure 2). In other words, China was in the emerging and rapid development stages over our study period while Japan was in the matured stage with only some minor refinement in its HSR system. As much longer time has elapsed for the civil aviation markets in Japan to respond to HSR development, we are expecting a much milder impact in Japan than in China.

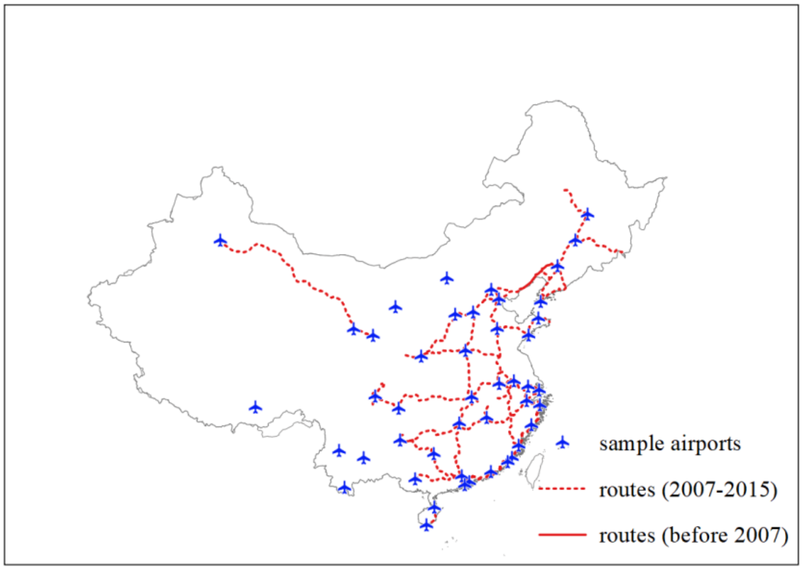


Figure 1 HSR development in China over 2007-2015

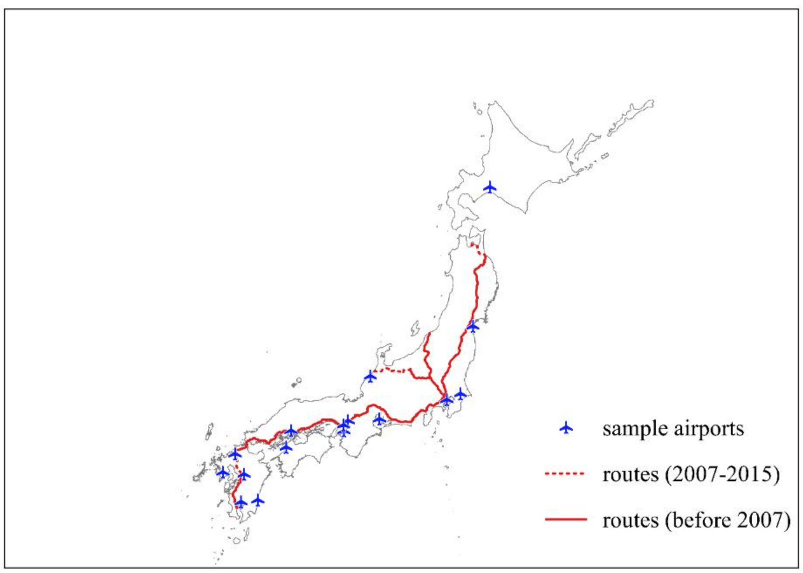


Figure 2 HSR development in Japan over 2007-2015

Third, China and Japan have very different HSR infrastructure network due to the territorial difference between these two countries. By the end of 2015, China's HSR has developed into a network of four vertical corridors and four horizontal corridors together with many branch lines (Figure 1). Therefore, China's HSR network appears to be a grid without a clear central node. Japan's network is simpler, and Tokyo is the obvious central node (Figure 2). This tree or star-like structure is quite common in other countries with significant HSR development due to the small geographic scope that needs to be covered by the HSR system. This difference in network structure can cause a variation in the correlation among different centrality measures discussed in Section 2.2. In general, degree and harmonic centralities are more likely to have stronger correlation in the tree or star-like structure than in the grid-like structure. In other words, differentiated results between connectivity and accessibility are more likely to generate differentiated results in the context of China.

2.2 Centrality measures

Centrality, developed by Freeman (1978), is a fundamental concept in network analysis to evaluate the importance of a node in a network. Among various measures of centrality, degree centrality and closeness centrality are the most commonly used to analyze transportation networks. Degree centrality can be interpreted as a node's connectivity in the network and closeness centrality may be interpreted as a node's accessibility by others in the network (e.g. Jiao et al., 2017; Wang et al., 2011; Wong et al., 2019). However, closeness centrality does not behave well in networks with disconnected components.[5] Therefore, given that HSR network is not fully connected in its early stage of development, especially in China, following Boldi and Vigna (2014), we use the natural modification of closeness centrality, i.e. harmonic centrality, proposed by Marchiori and Latora (2000). Both centralities can be calculated based on the information of the HSR infrastructure network, i.e. the physical HSR tracks. However, infrastructure only tells the potential of improving accessibility and its full potential may be achieved only when adequate services are provided (Moyano et al., 2018) and the quality of the service is as important as the infrastructure (Moyano et al., 2019). Thus, in this study, centralities are calculated based on HSR

[5] Closeness centrality is associated with the inverse of the sum of distances from the node in concern to all the other nodes in the network. As the distance (or travel time) between nodes in disconnected components of a network is infinite, the closeness centrality will be zero for all the nodes in the network.

service schedule data. This is especially important because some small HSR stations have very limited HSR services.

Degree is a straightforward centrality measure that quantifies the number of neighbors a node has. A node with high degree centrality has direct connections to many other nodes in the network. In this study, we use degree centrality to indicate the connectivity of an airport city to other cities in the HSR network. The degree centrality of airport city *i* is defined as:

$$C_D(i) = \sum_{j=1}^{N} a_{ij} \tag{1}$$

where a_{ij} indicates the connection between airport city *i* and prefecture-level HSR stations j. Thus, $a_{ij} = 1$ if there is a direct HSR service between nodes *i* and j, and $a_{ij} = 0$ otherwise. N denotes the total number of prefecture-level HSR stations in the networks. We define that two cities are directly connected via HSR service as long as passengers can travel from one city to the other without changing the trains. In addition, if a city pair is only served in one direction but not in the other, we assume these two cities are not directly connected.

Harmonic centrality comes from the idea of taking the harmonic mean of the node-pair distances. The harmonic centrality of airport city *i* is defined as:

$$C_H(i) = \sum_{j}^{N} \frac{1}{d(i,j)} \tag{2}$$

where $d(i,j)$ is the shortest distance (travel time in this study) between airport city i and prefecture-level HSR station j by using the HSR services and we set $d(i,j) = \infty$ if there is no direct HSR service between i and j. Although distance is widely used to measure $d(i,j)$, travel time may be more appropriate in the case of HSR network, because the maximum operating speed varies across different HSR lines (Wang et al., 2018). The shortest trip time is chosen to construct $d(i,j)$, whenever there exist multiple schedules between two cities and hence different scheduled trip times.

2.3 Model specifications

Throughout the analysis, we treat airports in China and those in Japan as two samples. We conduct regression analysis for each sample to characterize the relationship between airport-level passenger traffic and various HSR related variables, including the centrality measures defined in

Section 2.1 and the intermodal linkage between the airport and HSR station. Eq. (3) is the main empirical model:

$$PXG_{it} = \alpha_0 + \alpha_1 HSR_{it}^{Centrality} + \alpha_2 AirHSR_{it} + \alpha_3\left(HSR_{it}^{Centrality} \times AirHSR_{it}\right) + \gamma_1 POP_{it} + \gamma_2 GDP\_POP_{it} + \gamma_3 LCC_{it} + \gamma_4 FuelPrice_{it} + \gamma_5 Compete_{it} + \gamma_6 Year2008_{it} + \gamma_7 Year2009_{it} + \gamma_8 Year2011_{it} + \mu_i + \epsilon_{it} \quad (3)$$

where PXG_{it} is passenger throughput at airport *i* in year *t*. $HSR_{it}^{Centrality}$ is one of the HSR centrality measure, degree (SDgr) or harmonic (SHmc), of the city where airport *i* locates in year *t*. $AirHSR_{it}$ is a binary variable that equals to 1 if there is an intermodal linkage between airport *i* and an HSR station in year *t*. We include an interactive term between the centrality index and air-HSR intermodal linkage, $HSR_{it}^{Centrality} \times AirHSR_{it}$, to capture the possible feeding effect of HSR because of the convenient transfer between the airport and HSR station, and we expect the coefficient of this interactive term to be positive. We control for population size (POP), real GDP per capita (GDP_POP), low-cost carrier operation (LCC) and jet fuel price (FuelPrice). In addition, we also include airport competition (Compete) and demand shocks indicated by Year2008 (for China sample), Year2009 (for both China and Japan sample) and Year 2011 (for Japan sample) as control variables. Detailed construction of these control variables is described in Section 3. u_i is the airport fixed effect to control for unobservable airport-specific characteristics.[6] ϵ_{it} refers to the error term of airport *i* at time *t*. In this study, all variables are measured on the annual basis.

Route-level studies in the literature have revealed the relevance of origin-destination market distance to the impact of HSR on air services (refer to Dobruszkes and Givoni, 2013, for a literature review on some earlier studies). Although HSR has lower speed than air transport, the station access time and pre-departure processing time of HSR are in general shorter than air. Together with lower vulnerability to bad weather, HSR can have advantage over air in short-haul markets. According to Dobruszkes et al.'s (2014) EU-wide study, the impact of HSR travel time on air services diminishes sharply between 2 and 2.5 hours of HSR travel time, suggesting that there is a cutoff somewhere around a rail distance of 500km below which the impact of HSR on airlines is most remarkable. In China, HSR provides extensive long-haul services due to the country's large

[6] We estimated both fixed effect and random effect models. The Hausman test rejects the hypothesis that there is no difference between fixed effect estimator and random effect estimator. Therefore, random effect model may produce inconsistent estimations and is not applied in this study.

geographic scope and its ticket price is substantially lower than air. As a result, these two modes can compete in markets up to 1000km, which has been confirmed by several recent studies in China (e.g. Wan et al., 2016; Zhang et al., 2017; Zhang et al., 2018). Inspired by these findings, we incorporate the role of distance into the study by constructing three sub-measures of degree centrality for each airport *i*. Taking the city of airport *i* as the center, we divide all the other cities in the HSR network into three zones according to their HSR route distance to airport city *i*: HSR dominant zone (0-500km), HSR subdominant zone (500-1000km) and HSR non-dominant zone (over 1000km). Then, for each zone, we construct one sub-measure of degree centrality by considering cities in the respective zone only. That is, airport *i*'s degree centrality of the HSR dominant zone is the summation of a_{ij} across all *j* belonging to this zone. Subsequently, these three sub-measures are named as SDgr0-500, SDgr500-1000 and SDgr1000+, respectively. In the case of Japan, since the HSR service between Tokyo and Hakata is the only one that exceeds 1000km and is relevant to airports in our sample, we merge HSR non-dominant zone into subdominant zone by adding SDgr 500-1000 and SDgr 1000+ together and creating variable, SDgr 500+, for Japan. The correlation between airport traffic and degree centrality may deteriorate as we move from HSR dominant zone to HSR non-dominant zone.

Albalate et al. (2015) suggest that HSR has differentiated impacts on hub and non-hub airports and the availability of on-site HSR station may play a role in hub airport traffic. Therefore, to distinguish the HSR's effects on hub and non-hub airports, we extend Eq. (3) into Eq. (4) by incorporating the hub status of airport and introducing a three-way interaction term $HSR_{it}^{Centrality} \times AirHSR_{it} \times Hub_{it}$ to identify whether or not hub airports benefit more from the linkage between HSR stations and airports. Hub_{it} is a dummy variable that indicates the hub status of airport *i* at time *t*. In this study, we consider Beijing, Shanghai, Guangzhou and Shenzhen as hubs for China, and Haneda, Narita, Kansai and Itami as hubs for Japan.

$$\begin{aligned} PXG_{it} = {} & \beta_0 + \beta_1 HSR_{it}^{Centrality} + \beta_2 AirHSR_{it} + \beta_3 Hub_{it} \\ & + \beta_4 (HSR_{it}^{Centrality} \times AirHSR_{it}) + \beta_5 (HSR_{it}^{Centrality} \times Hub_{it}) \\ & + \beta_6 (AirHSR_{it} \times Hub_{it}) + \beta_7 (HSR_{it}^{Centrality} \times AirHSR_{it} \times Hub_{it}) \\ & + \delta_1 POP_{it} + \delta_2 GDP\_POP_{it} + \delta_3 LCC_{it} + \delta_4 FuelPrice_{it} + \delta_5 Compete_{it} \\ & + \delta_6 Year2008_{it} + \delta_7 Year2009_{it} + \delta_8 Year2011_{it} + \mu_i + \epsilon_{it} \end{aligned} \tag{4}$$

In addition to using total passenger traffic as the dependent variable, to better understand how different types of traffic are associated with HSR development, we also fit models similar to Eq. (3) and Eq. (4) by replacing the dependent variable with domestic passenger traffic or international passenger traffic, respectively. Given that HSR tends to substitute air transport in domestic short-haul markets, most of the studies in the literature exclude international traffic. However, to assess HSR's role as a complement and feeder to air transport, it is essential to consider the international markets where HSR tends to have limited access.

3. Data and variable construction

We consider all major Chinese mainland and Japanese airports with annual throughput over two million passengers in 2015. That is, there are 48 relevant Chinese airports covering all the provincial capitals and sub-provincial cities in mainland China and 18 Japanese airports from majority of large cities in Japan. Among the 48 Chinese airports, Shanghai Pudong Airport (PVG) and Shanghai Hongqiao Airport (SHA) are merged into one airport entity (SHPV) because both airports are operated under the same authority and only aggregated international passenger traffic data are available for these two airports. Beijing Nanyuan Airport (NAY) is excluded due to lack of detailed information. In the case of Japan, Naha Airport (OKA) and Ishigaki Airport (ISG) are removed since they are located on Ishigaki Island which is not served by HSR. As a result, we have in our panel dataset 46 Chinese airports and 16 Japanese airports covering the period of 2007-2015. Locations of these sample airports are shown in Figures 1 and 2. These airports on average account for 92.2% of China's total passenger traffic and 81.7% of Japan's total passenger traffic. During the sampling period, 41 out of the 46 airport cities in China started HSR services and 12 airport cities in Japan are served by the Shinkansen system (Appendix A).

Various data sources are used to obtain airport-level traffic data. In the case of China, there is no single accurate data source which provides consistent information about total, domestic and international traffic of all the sampled Chinese airports. Thus, total passenger traffic (PAX) data is obtained directly from Statistical Data on Civil Aviation of China (2007-2015). China's Port-of-Entry Yearbook provides the number of international passengers using the airport as the point of entry in the previous year and therefore this information in the 2008-2016 versions is extracted to measure international passenger traffic (PAX_International). Domestic passenger traffic

(PAX_Domestic) in China is estimated by subtracting the international passenger traffic from total passenger traffic of each Chinese airport.[7] The total, domestic and international passenger traffic data for airports in Japan is available from Japanese Ministry of Land, Infrastructure, Transport and Tourism. Table 1 summarizes the descriptive statistics of total, domestic and international traffic, variable of interest and control variables.

Table 1 Descriptive statistics of all the variables

	China					Japan				
Variable	**Obs**	**Mean**	**Std.**	**Min**	**Max**	**Obs**	**Mean**	**Std.**	**Min**	**Max**
Dependent variable										
PXG (millions)	414	12.712	16.208	0.700	99.189	144	12.564	16.433	1.717	75.255
PXG_Domestic (millions)	414	11.051	12.267	0.681	67.363	144	9.133	14.307	1.143	64.994
PXG_International (millions)	414	1.660	4.422	0	32.359	144	3.431	7.118	0	31.104
Variable of interest										
SDgr	414	18.384	23.866	0	113	144	22.208	20.387	0	68
SDgr0-500	414	5.715	6.184	0	26	144	18	15.799	0	53
SDgr500-1000 or SDgr500+ [a]	414	6.290	8.540	0	43	144	4.208	5.174	0	17
SDgr1000+	414	7.217	12.614	0	67	-	-	-	-	-
SHmc	414	0.079	0.081	0	0.319	144	0.229	0.237	0	0.790
AirHSR	414	0.082	0.275	0	1	144	0.375	0.486	0	1
Control variable										
POP (millions)	414	7.446	5.571	0.465	30.166	144	5.091	4.031	1.104	13.515
GDP_POP (10 thousands in CNY or millions in JPY)	414	4.393	2.081	0.601	11.449	144	4.248	1.309	3.068	7.857
LCC	414	0.085	0.279	0	1	144	0.604	1.111	0	4
FuelPrice (100$ per barrel in 2000 USD)	414	1.029	0.232	0.657	1.276	144	1.029	0.232	0.657	1.276
Compete	414	0.565	1.057	0	6	144	0.979	0.780	0	2
Year2008	414	0.111	0.315	0	1	-	-	-	-	-
Year2009	414	0.111	0.315	0	1	144	0.111	0.315	0	1
Year2011	-	-	-	-	-	144	0.111	0.315	0	1

Note: a. SDgr500+ applies to the case of Japan only.

As mentioned in Section 2, there are three variables of interest: HSR connectivity of airport city (degree centrality, SDgr), HSR accessibility of airport city (harmonic centrality, SHmc) and air-HSR intermodal linkage (AirHSR). SDgr and SHmc are calculated based on HSR timetables, namely National Rail Timetable of China (July edition, 2007-2015) published by Ministry of

[7] Another possible source of domestic traffic data is Statistical Data on Civil Aviation of China, but this source only includes traffic data for major (not all) route segments. We have conducted robustness check for domestic traffic with this data source and the main results persist.

Railways of China and JR Timetable of Japan (March edition, 2007-2015) provided by Japan Railways Group. Since there are several editions of timetables each year, July edition is chosen for China and March edition is chosen for Japan. This is because majority of the newly opened HSR lines are launched around July 1st or December 31st in China and March in Japan during our observation period. Moreover, since HSR services started close to the end of a calendar year may have limited impacts on that year's air transport, we follow Wan et al. (2016) and assume that the "effective" start year of a particular new HSR service is one year after the actual start year if this service starts in the fourth quarter of a year. In calculating centralities, we consolidate all the stations into one when there are multiple HSR stations in a city.

Table 2 lists average SDgr and SHmc for each sampled airport across the sampling period, including connectivity to HSR dominant zone (SDgr 0-500), subdominant zone (SDgr 500-1000) and non-dominant zone (SDgr 1000+). One observation is that SDgr and SHmc provide similar but still different information. In China, Beijing, Shanghai, Wuhan, Nanjing, Wuxi, Zhengzhou and Hangzhou are the best connected to other cities via HSR. Each of them has an average SDgr over 40 during our observation period. Wuxi, Zhengzhou, Wuhan, Nanjing, Changsha and Hangzhou have higher values in SHmc. Cities with high SHmc tend to be located near the physical center of the HSR infrastructure network, since this SHmc reflects the distance from one node to all the other nodes in the HSR network, but this is not the case for cities with high SDgr, e.g. Beijing and Shanghai. In Japan, where HSR network structure looks like a line, Tokyo and Osaka are found to be the most important cities in both SDgr and SHmc. In general, connectivity and accessibility measures are highly correlated, and thus, we only include one of them in each regression analysis to avoid multi-collinearity issues. Consistent with our discussion in Section 2.1, this correlation is stronger in Japan (0.96) than in China (0.90) probably due to different network structure, which might explain the slightly differentiated impacts of connectivity and accessibility in China (refer to Appendix B for the pairwise correlations among all centrality indicators).

Table 2 Average HSR centralities over 2007-2015 period for each sampled airport city

China							Japan					
City	Airport code	SDgr	SDgr 0-500	SDgr 500-1000	SDgr 1000+	SHmc	City	Airport code	SDgr	SDgr 0-500	SDgr 500+	SHmc
Beijing	PEK	59.89	13.11	21.78	25.00	0.13	Tokyo	HND	62.67	46.78	15.89	0.77
Shanghai	SHPV	55.22	14.67	17.89	22.67	0.16	Tokyo	NRT	62.67	46.78	15.89	0.77
Wuhan	WUH	48.11	16.22	21.56	10.33	0.18	Osaka	ITM	35.11	31.00	4.11	0.26
Nanjing	NKG	45.00	15.78	15.78	13.44	0.18	Osaka	KIX	35.11	31.00	4.11	0.26
Wuxi	WUX	41.67	13.56	13.67	14.44	0.20	Fukuoka	FUK	30.78	22.11	8.67	0.23
Zhengzhou	CGO	40.89	16.56	18.22	6.11	0.19	Kobe	UKB	30.11	25.00	5.11	0.28
Hangzhou	HGH	40.67	15.44	14.78	10.44	0.16	Hiroshima	HIJ	26.11	22.56	3.56	0.26
Changsha	CSX	35.67	11.56	13.22	10.89	0.16	Nagoya	NGO	26.00	21.00	5.00	0.28
Jinan	TNA	35.22	13.22	12.33	9.67	0.15	Sendai	SDJ	21.11	21.11	0.00	0.27
Tianjin	TSN	32.78	9.11	12.33	11.33	0.14	Kagoshima	KOJ	12.89	9.56	3.33	0.12
Shijiazhuang	SJW	26.89	10.44	8.67	7.78	0.14	Kumamoto	KMJ	11.11	9.44	1.67	0.17
Nanchang	KHN	26.33	11.44	9.11	5.78	0.14	Komatsu	KMQ	1.67	1.67	0.00	0.02
Hefei	HFE	25.22	10.22	10.11	4.89	0.14	Sapporo	CTS	0.00	0.00	0.00	0.00
Fuzhou	FOC	24.89	6.22	8.33	10.33	0.10	Miyazaki	KMI	0.00	0.00	0.00	0.00
Ningbo	NGB	24.67	8.67	9.33	6.67	0.11	Matsuyama	MYJ	0.00	0.00	0.00	0.00
Guangzhou	CAN	24.44	7.00	5.22	12.22	0.12	Nagasaki	NGS	0.00	0.00	0.00	0.00
Qingdao	TAO	24.22	4.22	8.89	11.11	0.09						
Wenzhou	WNZ	21.22	6.22	9.22	5.78	0.09						
Shengyang	SHE	21.11	8.67	5.33	7.11	0.11						
Shenzhen	SZX	21.00	4.56	4.56	11.89	0.10						
Xiamen	XMN	18.33	4.33	6.00	8.00	0.08						
Quanzhou	JJN	18.11	4.89	6.78	6.44	0.09						
Xian	XIY	16.89	4.00	6.00	6.89	0.09						
Changchun	CGQ	15.89	6.11	4.33	5.44	0.08						
Taiyuan	TYN	15.56	4.89	7.11	3.56	0.10						
Harbin	HRB	15.00	3.44	5.22	6.33	0.06						
Chongqing	CKG	12.00	1.89	1.56	8.56	0.04						
Chengdu	CTU	11.56	3.22	0.67	7.67	0.04						
Guiyang	KWL	9.33	2.33	2.00	5.00	0.04						
Nanning	NNG	9.33	2.00	1.67	5.67	0.04						
Dalian	DLC	7.89	2.44	2.89	2.56	0.03						
Guilin	KWE	7.00	0.67	1.56	4.78	0.02						
Jieyang	SWA	6.44	2.22	1.67	2.56	0.04						
Yantai	YNT	2.22	0.33	1.11	0.78	0.02						
Zhuhai	ZUH	1.11	1.11	0.00	0.00	0.08						
Urumqi	URC	0.89	0.11	0.11	0.67	0.00						
Xining	XNN	0.89	0.44	0.11	0.33	0.01						
Lanzhou	ZGC	0.89	0.33	0.22	0.33	0.00						
Haikou	HAK	0.56	0.56	0.00	0.00	0.00						
Sanya	SYX	0.56	0.56	0.00	0.00	0.00						
Hohhot	HET	0.11	0.11	0.00	0.00	0.00						
Yinchuan	INC	0.00	0.00	0.00	0.00	0.00						
Jinghong	JHG	0.00	0.00	0.00	0.00	0.00						
Kunming	KMG	0.00	0.00	0.00	0.00	0.00						
Lijiang	LJG	0.00	0.00	0.00	0.00	0.00						
Lhasa	LXA	0.00	0.00	0.00	0.00	0.00						

Notes: To save space, we show the average centrality values only. Centrality values of individual years are available upon request. Cities are listed in descending order of their average connectivity (SDgr).

Zhang et al. (2018) use on-site HSR service to capture the complementary traffic feeding effect of HSR. They ignore the cases where on-site HSR services are not available but a convenient transfer between the airport and an HSR station in the city is available. Even without on-site HSR, air-HSR intermodal services may still be desirable when passengers have limited flight choices at other airports or air-to-air connections are not convenient. The latter is very likely the case in China due to severe flight delays at busy airports and cumbersome flight connecting procedures in general. The easiness to transfer between the airport and HSR station can be measured by the access time between HSR station and airport. However, as historical data of this access time is not available, we construct a dummy variable, AirHSR, instead to reflect the availability of a convenient and reliable connection between these two modes, including on-site or nearby HSR stations. Therefore, AirHSR equals to one if:

(1) The airport and HSR station are connected by any form of urban rail transit[8] with an exclusive right-of-way and separated from other road traffic of which the trip time is no more than 30 minutes; or

(2) The HSR station is located nearby the airport terminal (e.g. Shanghai Hongqiao Airport and Changchun Longjia Airport) or inside the airport terminal (e.g. Chengdu Shuangliu Airport and Guiyang Longdongpu Airport).

Otherwise, AirHSR equals to zero. Related information is obtained from various channels including news articles and airports' official websites. Control variables are constructed in the following ways.

- Population (POP): Larger population size in the airport's catchment area tends to generate higher air travel demand. This variable is measured by the number of permanent residents in an airport's catchment area. In the case of China, we define the catchment area of an airport as the city where the airport locates, and in the case of Japan, the catchment area is the prefecture in which the airport is situated.
- Real GDP per capita (GDP_POP): It is expected that higher GDP per capita implies higher income of a region and hence associates with higher air travel demand. The variable is constructed by taking the ratio between the real GDP in 2007 base and the population in an airport's catchment area. Population and real GDP data are gathered from National Bureau of Statistics of China and Cabinet of Japan.

[8] Compared with cars and buses, this form of transit is more reliable and is less likely to be influenced by traffic congestion and other exogenous factors, which is quite important for passengers who are connecting between the flight and HSR ride.

- Low-cost carrier operation (LCC): Inspired by Albalate and Fageda (2016), we use the number of low-cost carriers using the airport as their base to capture the influence of low-cost carriers on airport traffic. The relevant information is captured by examining news and airport reports. We expect that LCC will be positively associated with airport passenger traffic.
- Jet fuel price (FuelPrice): As jet fuel accounts for a substantial share of airlines' operating costs, it can affect airfares and hence travel demand (Ito and Lee, 2005). Therefore, jet fuel price is widely used as a control variable for air traffic volume. Clewlow et al. (2014) find that airport traffic can experience a substantial decrease as the jet fuel price increases and thus we expect a negative coefficient of this variable. Jet fuel price data is collected from IATA Fact Sheet (Fuel) 2018.
- Airport competition (Compete): This variable aims to capture the relationship between an airport's traffic and the presence of other airports nearby, which could be the outcome of airport competition. Following Bel and Fageda (2010), we use number of airports located within a radius of 100km as a proxy for the "upper level" of potential competition among airports (Adler and Liebert, 2014).[9] To focus on airports which do have a potential to compete, we only take into account rival airports with an annual passenger number over 2 million in 2015. Most studies (e.g. Bel and Fageda, 2010; Adler and Liebert, 2014; Randrianarisoa et al. 2015) use a cutoff of 150,000 passengers per year as this figure is used by Eurostat to distinguish main and small commercial airports. Considering the higher population density in China and Japan, we plot the distribution of traffic among airports and reveal that 2 million is a more reasonable cutoff in our context.
- Demand shocks (Year2008, Year2009, Year2011): We use several dummy variables to indicate years when exogenous events occurred and might substantially affect air transport demand. Years 2008 and 2009 are selected for airports in China and years 2009 and 2011 are chosen for airports in Japan. Year 2008 controls for the effect of Beijing Olympic Games in China. Year 2009 controls for the effect of global financial crisis

[9] More rigorous measures of airport competition intensity can be constructed by considering alternative origin-destination routes offered by rival airports nearby. This method requires more detailed route-level information which is not available for this study.

which started near the end of 2008 and had most substantial impact on air transport in 2009. Year 2011 controls for the effect of Tohoku earthquake and tsunami in Japan.

4. Regression results

4.1 Analysis based on the main model

This section reports the regression results based on Eq. (3) for China and Japan respectively. Table 3 presents the results for China, using total passenger traffic as the dependent variable. The estimated coefficients of control variables follow our expectation. Population and real GDP per capita are both positively correlated with airport traffic with a high level of statistical significance across all models, suggesting that airports located in more developed cities induce more air travel demand. Both jet fuel price and airport competition negatively correlate with airport traffic. Airport traffic is positively correlated with the status of a low-cost carrier base. Although the coefficients are not statistically significant, major multinational events such as 2008 Olympic Games might have some positive impact on airport traffic and global financial crisis (captured by Year2009) seems to have some negative effect as well.

Table 3 Regression results based on Eq.(3) (DV = total passenger traffic, China)

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
HSR zones		0-500	500-1000	1000+			0-500	500-1000	1000+	
POP	5.076***	5.301***	5.301***	4.702***	5.066***	4.862***	5.033***	5.021***	4.620***	4.835***
	(0.353)	(0.331)	(0.336)	(0.349)	(0.339)	(0.339)	(0.324)	(0.331)	(0.334)	(0.330)
GDP_POP	1.973***	2.292***	2.217***	1.598***	2.035***	1.874***	2.104***	2.022***	1.607***	1.888***
	(0.244)	(0.225)	(0.224)	(0.233)	(0.246)	(0.234)	(0.221)	(0.221)	(0.224)	(0.239)
LCC	2.468***	2.266***	2.197***	2.486***	2.462***	1.682**	1.755**	1.717**	1.572**	1.759**
	(0.815)	(0.799)	(0.806)	(0.815)	(0.814)	(0.788)	(0.782)	(0.789)	(0.792)	(0.795)
FuelPrice	-2.935***	-3.189***	-3.316***	-1.724**	-2.910***	-2.394***	-2.731***	-2.788***	-1.561**	-2.440***
	(0.800)	(0.689)	(0.711)	(0.828)	(0.747)	(0.770)	(0.675)	(0.698)	(0.792)	(0.728)
Compete	-6.211***	-6.774***	-5.697***	-6.224***	-6.468***	-5.177***	-5.932***	-4.930***	-5.210***	-5.630***
	(1.394)	(1.370)	(1.378)	(1.394)	(1.397)	(1.340)	(1.334)	(1.3449)	(1.341)	(1.356)
Year2008	0.455	0.457	0.548	0.071	0.385	0.258	0.319	0.386	0.001	0.210
	(0.502)	(0.476)	(0.482)	(0.510)	(0.488)	(0.481)	(0.462)	(0.4694)	(0.487)	(0.473)
Year2009	-0.719	-0.795	-0.780	-0.438	-0.772	-0.518	-0.598	-0.576	-0.333	-0.595
	(0.505)	(0.487)	(0.490)	(0.508)	(0.506)	(0.483)	(0.473)	(0.477)	(0.485)	(0.489)
SDgr	-0.017	-0.267***	-0.131***	0.027		-0.028**	-0.262***	-0.123***	-0.012	
	(0.012)	(0.063)	(0.034)	(0.021)		(0.012)	(0.060)	(0.034)	(0.021)	
SHmc					-7.642*					-9.162**
					(4.372)					(4.254)
AirHSR						0.630	1.307	1.486	0.909	1.046
						(0.958)	(1.076)	(0.919)	(0.871)	(1.096)
SDgr × AirHSR						0.069***	0.205**	0.152**	0.121***	
						(0.018)	(0.098)	(0.067)	(0.031)	
SHmc × AirHSR										16.903**
										(6.911)

Constant	-27.06***	-28.34***	-29.20***	-24.39***	-26.86***	-26.17***	-26.72***	-27.49***	-24.48***	-25.54***
	(2.390)	(2.194)	(2.315)	(2.339)	(2.257)	(2.291)	(2.144)	(2.273)	(2.245)	(2.192)
Airport FE	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
N	414	414	414	414	414	414	414	414	414	414
R^2	0.426	0.425	0.435	0.421	0.426	0.442	0.437	0.446	0.437	0.438

Note: Standard errors are in parentheses. *p < 0.1, ** p < 0.05, ***p < 0.01.

Columns (1)-(5) in Table 3 show the average effect of HSR connectivity and accessibility without differentiating airports with and without air-HSR intermodal linkage. Columns (1)-(4) present the results using SDgr, SDgr0-500, SDgr500-1000 and SDgr1000+, respectively, as the centrality measures. On average, airport traffic in China is negatively correlated with the airport city's HSR accessibility but the relationship with HSR connectivity is highly affected by the distance. Columns (2) and (3) suggest that increasing connectivity to HSR dominant zones and sub-dominant zones may associate with statistically significant reduction in airport traffic. In particular, adding one direct HSR connection to cities within 500km implies a reduction of 0.267 million passengers per year. Whilst, there will be a much milder drop in passenger throughput (0.131 million per year) if the airport city adds one HSR connection to a city located within 500-1000km. However, connectivity to the HSR non-dominant zone has little correlation with airport total traffic (column 4), which may contribute to the statistically insignificant coefficient of SDgr in column (1). This finding indicates that the impact of HSR deteriorates in its service distance, which is consistent with the earlier route-level studies in China (e.g. Wan et al., 2016; Chen, 2017). Column (5) reports results using SHmc as the centrality measure. The negative coefficient of SHmc suggests that improving the proximity of the airport city to the other cities by HSR may on average resulting in a decline in airport passenger traffic.

Columns (6)-(10) in Table 3 report the estimations by following Eq. (3) exactly to take into account air-HSR intermodal linkage and its interaction with SDgr or SHmc. Coefficients of the interaction term are all positive and statistically significant. It suggests that a good connection between airport and HSR station may bring an extra positive impact on airport traffic in spite of the traffic reduction associated with improved HSR connectivity and accessibility. Moreover, this moderation effect also depends on distance, because the coefficients of the interaction term have a decreasing magnitude as one moves from column (7) to column (9). This finding is consistent to Zhang et al. (2018).

A similar regression analysis is conducted in the case of Japan and the results are presented in Table 4. Without considering the role of air-HSR linkage, we observe no statistically significant relationship between HSR centralities and airport traffic (columns 1-4). Even after controlling for air-HSR linkage (columns 5-8), the coefficients of SDgr and SHmc are not statistically significant. This can be partially explained by the fact that HSR network has been highly developed in Japan since the 1990s and hence the competition between HSR and air transport has reached a certain equilibrium years ago. As discussed in Section 2.1, the relatively minor expansion in Japanese HSR system during the sampling period is not substantial enough to break this equilibrium. This can be seen from the data (Appendix C), as many Japanese airport cities in the sample have limited inter-temporal variation in HSR connectivity and accessibility. This result is consistent with the conclusion made by Castillo-Manzano et al. (2015) that as time passes by and new lines are added, the air-HSR substitution rate diminishes after reaching its maximum. However, we still reveal an important role of air-HSR intermodal linkage from the coefficients of the interaction terms in columns (5), (6) and (8), while the one in column (7) is not statistically significant.

Table 4 Regression results based on Eq. (3) (DV = total passenger traffic, Japan)

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
HSR zones		0-500	500+			0-500	500+	
POP	3.491	3.304	3.894*	3.515	2.429	2.544	4.244*	2.491
	(2.219)	(2.220)	(2.216)	(2.216)	(2.215)	(2.168)	(2.432)	(2.300)
GDP_POP	2.204**	2.110***	2.576**	2.203**	1.872*	1.964**	2.713**	2.008**
	(1.005)	(1.002)	(1.013)	(1.009)	(0.982)	(0.960)	(1.106)	(1.011)
LCC	1.524***	1.528***	1.610***	1.530***	1.234***	1.223***	1.562***	1.609***
	(0.357)	(0.355)	(0.358)	(0.356)	(0.393)	(0.383)	(0.396)	(0.392)
FuelPrice	-1.389**	-1.359**	-1.267**	-1.385**	-1.473***	-1.318**	-1.246**	-1.410**
	(0.567)	(0.566)	(0.570)	(0.567)	(0.550)	(0.539)	(0.581)	(0.563)
Compete	2.438**	2.482**	2.578**	2.446**	-4.512*	-2.548	2.679	-2.827
	(1.155)	(1.151)	(1.151)	(1.155)	(2.611)	(1.926)	(2.665)	(3.088)
Year2009	-0.902*	-0.882*	-0.901*	-0.904*	-0.907**	-0.829*	-0.886*	-0.905*
	(0.470)	(0.470)	(0.467)	(0.470)	(0.455)	(0.447)	(0.475)	(0.467)
Year2011	-1.337***	-1.358***	-1.234***	-1.333***	-1.432***	-1.432***	-1.239***	-1.348***
	(0.367)	(0.365)	(0.367)	(0.366)	(0.359)	(0.351)	(0.371)	(0.367)
SDgr	0.013	0.035	-0.131		-0.018	-0.022	-0.134	
	(0.030)	(0.035)	(0.100)		(0.030)	(0.037)	(0.119)	
SHmc				0.904				-1.104
				(2.343)				(2.543)
AirHSR					-6.922***	-6.570***	0.425	-3.207*
					(2.257)	(1.864)	(1.120)	(1.743)
SDgr×AirHSR					0.225***	0.253***	-0.041	
					(0.070)	(0.067)	(0.226)	
SHmc×AirHSR								11.457*
								(5.831)
Constant	-16.48	-15.56	-19.68	-16.54	-2.49	-5.35	-22.17	-5.42
	(12.88)	(12.87)	(12.96)	(12.881)	(13.34)	(12.705)	(15.477)	(14.079)
Airport FE	Y	Y	Y	Y	Y	Y	Y	Y
N	144	144	144	144	144	144	144	144
R^2	0.734	0.733	0.731	0.735	0.746	0.766	0.724	0.775

Note: Standard errors are in parentheses. *p <0.1, ** p<0.05, ***p<0.01;

4.2 Net effects by air-HSR intermodal linkage

Although air-HSR intermodal linkage may moderate the negative impact of HSR expansion in both China and Japan, it is unclear whether this moderation effect can offset the traffic reduction and eventually lead to a positive correlation between airport traffic and HSR centralities. Thus, we calculate the "net effect" of HSR connectivity and accessibility by taking partial derivative of Eq.(3) with respect to the corresponding HSR centrality measure. That is, the net effect of a particular HSR centrality can be written as:

$$\frac{\partial PXG_{it}}{\partial HSR_{it}^{Centrality}} = \alpha_1 + \alpha_3 AirHSR_{it}$$

Table 5 presents such net effects and their statistical significance by distinguishing airports with and without air-HSR intermodal linkage. The top part of Table 5 is for total passenger traffic in China and Japan. To shed some lights on the possible reasons for different results regarding total passenger traffic, we conduct similar regression analysis for domestic and international passenger traffic. In the middle and bottom parts of Table 5, we present the "net effect" from these models to facilitate the comparison with total passenger traffic and to save space. The details of the model estimation are available in Appendix D.

Table 5 Net effects on passenger traffic by air-HSR linkage

Dependent variable	HSR centrality	AirHSR	China		Japan	
			Net effect	Std. Err.	Net effect	Std. Err.
Total Passenger	SDgr	0	-0.028**	0.012	-0.018	0.030
		1	0.041**	0.020	0.206***	0.067
	SDgr0-500	0	-0.262***	0.061	-0.021	0.036
		1	-0.057	0.114	0.231***	0.061
	SDgr500-1000	0	-0.123***	0.034	-0.134	0.119
	SDgr500+[a]	1	0.029	0.072	-0.176	0.204
	SDgr1000+	0	-0.012	0.021	-	-
		1	0.109***	0.031	-	-
	SHmc	0	-9.162**	4.254	-1.104	2.543
		1	7.740	7.615	10.352*	5.337
Domestic Passenger	SDgr	0	-0.025***	0.010	-0.015	0.018
		1	-0.007	0.016	0.037	0.040
	SDgr0-500	0	-0.217***	0.049	-0.014	0.022
		1	-0.254***	0.092	0.048	0.038
	SDgr500-1000	0	-0.095***	0.027	-0.095	0.069
	SDgr500+[a]	1	-0.073	0.058	-0.134	0.119
	SDgr1000+	0	-0.014	0.017	-	-
		1	0.023	0.026	-	-
	SHmc	0	-7.605**	3.456	-1.109	1.502
		1	-9.573	6.187	2.556	3.152

International Passenger	SDgr	0	-0.003	0.004	-0.002	0.022
		1	0.048***	0.007	0.169***	0.049
	SDgr0-500	0	-0.044**	0.021	-0.007	0.026
		1	0.197***	0.040	0.182***	0.045
	SDgr500-1000	0	-0.028**	0.012	-0.038	0.088
	SDgr500+[a]	1	0.102***	0.025	-0.042	0.151
	SDgr1000+	0	0.002	0.007	-	-
		1	0.085***	0.010	-	-
	SHmc	0	-1.556	1.441	0.005	1.872
		1	17.314***	2.580	7.796**	3.929

Note: a. SDgr500+ applies to the case of Japan only. *p < 0.1, ** p < 0.05, ***p < 0.01.

In China, raising HSR *accessibility* by 0.01 (about 12.6% of the average SHmc) implies a net reduction of 0.092 million passengers at airports without air-HSR linkage but it has no statistically significant relationship with total traffic at airports with air-HSR linkage. An increase in HSR *connectivity* implies a net decrease in total traffic at airports without a good linkage to HSR stations but a net increase in total traffic at airports with air-HSR linkage. In a word, HSR accessibility and connectivity generate different net effects. A comparison between domestic and international traffic reveals the underlying reasons. In particular, when there is air-HSR linkage, HSR connectivity to all the three zones, SDgr0-500, SDgr500-1000 and SDgr1000+, are positively correlated with international passengers. Meanwhile, only SDgr0-500 has a statistically significant negative relationship with domestic passengers. As a result, the positive impact on international passengers dominates, leading to a net increase in airport traffic. HSR accessibility, on the other hand, measures the overall closeness of the airport city to other cities by HSR. Thus, high accessibility suggests high connectivity to cities within the HSR dominant zone (SDgr0-500) relative to cities located in other zones. As a result, cities with high HSR accessibility suffers too much domestic traffic reduction which cannot be offset by an increase in international passengers, leading to a net reduction in total airport traffic. The above also explains why the positive effect of air-HSR linkage on total traffic is mainly driven by adding HSR connection to cities over 1000km away (i.e. increasing SDgr1000+), instead of cities within 1000km, because when adding connectivity to cities within 1000km, the negative impacts on domestic passengers offsets the positive impacts on international passengers.

In Japan, HSR accessibility and connectivity tend to generate similar net impacts though the level of statistical significance is lower with HSR accessibility. This is consistent with the higher correlation between SDgr and SHmc in Japan than in China as mentioned in Section 3. Increasing

HSR accessibility may raise airport traffic when the airport has air-HSR linkage but has little impact otherwise. Similar conclusion can be drawn on increasing HSR connectivity with only one exception: connections to cities located over 500km away are not associated with airport traffic regardless the availability of air-HSR intermodal linkage. In fact, neither domestic traffic nor international traffic is associated with HSR connectivity or accessibility when the airport has no air-HSR linkage. Whilst, as air-HSR intermodal linkage facilitates HSR to feed international flights, international traffic becomes positively correlated with several HSR centrality measures.

A closer look at the magnitudes of the net effects reveals another interesting difference between China and Japan. Taking SDgr as an example, when there is no air-HSR linkage, the net effect of SDgr is -0.028 in China and -0.018 (not statistically significant) in Japan. When there exists air-HSR linkage, the coefficient is 0.041 in China and 0.206 in Japan. A similar pattern can be observed for the net effects of SHmc. Thus, in summary, compared with Japan, HSR network development in China has a stronger substitution effect, causing much milder total traffic increase when air-HSR linkage is provided.

4.3 Role of airport hub status

This section distinguishes hub and non-hub airports in the analysis by fitting Eq. (4). Again, the details about model estimation are available in Appendix E. By taking partial derivative of Eq.(4) with respect to HSR centrality, the net effect of HSR network development depends on not only the hub status but also the air-HSR linkage and it can be written as:

$$\frac{\partial PXG_{it}}{\partial HSR_{it}^{Centrality}} = \beta_1 + \beta_4 AirHSR_{it} + \beta_5 Hub_{it} + \beta_7 AirHSR_{it} \times Hub_{it}$$

Table 6 reports the net effects in the context of China by distinguishing airport hub status as well as the availability of air-HSR linkage. The upper part of Table 6 reports the net effects of increasing SDgr and the lower part reports the net effects of increasing SHmc. Each number under the column of "net effect" represents the amount of such net effects for different scenarios. An airport will fall into one of the four scenarios: (1) non-hub airport without air-HSR linkage (AirHSR = 0 and Hub = 0), (2) hub airport without air-HSR linkage (AirHSR = 0 and Hub = 1), (3) non-hub airport with air-HSR linkage (AirHSR = 1 and Hub = 0) and (4) hub airport with air-HSR linkage (AirHSR = 1 and Hub = 1). Therefore, the number 0.052 in the first "net effect" column means that if SDgr increases by one, an average hub airport without air-HSR linkage will have 0.052 million more passengers.

Table 6 Net effects on passenger traffic by air-HSR linkage and hub status (China)

HSR centrality	Scenario		Total Passenger		Domestic Passenger		International Passenger	
	AirHSR	Hub	Net effect	Std. Err.	Net effect	Std. Err.	Net effect	Std. Err.
SDgr	0	0	-0.023**	0.011	-0.023**	0.010	0.0007	0.002
	0	1	0.052**	0.022	0.010	0.020	0.041***	0.005
	1	0	-0.030	0.021	-0.035*	0.019	0.005	0.004
	1	1	0.160***	0.032	0.046	0.029	0.113***	0.007
SHmc	0	0	-8.666**	3.863	-7.393**	3.417	-1.273	0.802
	0	1	12.616	11.842	1.467	10.47	11.14***	2.460
	1	0	-17.56**	7.580	-17.75***	6.705	0.189	1.574
	1	1	67.83***	16.97	3.731	15.01	64.10***	3.526

Note: *$p < 0.1$, ** $p < 0.05$, ***$p < 0.01$.

Table 6 reveals the differentiated impacts on hub and non-hub airports. In general, both HSR connectivity and accessibility tend to have negative or statistically insignificant net effects on non-hub airports. This negative impacts are particularly strong in domestic markets and there is no substantial increase in international traffic even when air-HSR linkage is provided. On the contrary, both centrality measures tend to positively correlate with international and total traffic at hub airports with little impact on domestic traffic. In other words, HSR network development enlarges the traffic difference between hub and non-hub airports by draining traffic from non-hub airports and adding traffic to hub airports, and as a result further concentrates passenger traffic at a few large airports. Provision of air-HSR linkage is likely to enhance the feeder role of HSR for hub airports in the sense that hub airports with air-HSR linkage enjoy substantially more traffic increase than those without air-HSR linkage. However, air-HSR linkage does not always benefit non-hub airports and the net impact depends on the centrality indicator in concern. In particular, if SDgr increases, the total traffic change at non-hub airports with air-HSR linkage is statistically insignificant. However, if SHmc increases, these airports may experience more traffic loss comparing with the case without air-HSR linkage. Consequently, as HSR connectivity or accessibility improves, hub airports with air-HSR linkage would experience the highest level of traffic increase, followed by hub airports without air-HSR linkage. Nevertheless, non-hub airports *without* air-HSR linkage would experience the strongest traffic reduction if HSR connectivity increases while non-hub airports *with* air-HSR linkage would experience the strongest traffic reduction if HSR accessibility improves.

Table 7 reports the net effects of HSR connectivity and accessibility in the context of Japan. One major difference between China and Japan is that in Japan, the main results are driven by the air-HSR linkage instead of hub status. That is, non-hub airports with good air-HSR linkage can also experience an increase in international traffic and consequently an increase in total traffic. Regarding hub airports, although those with air-HSR linkage may experience substantial traffic increase driven mainly by international traffic, those without air-HSR linkage may experience little traffic increase due to loss of domestic passengers. Therefore, in Japan, the only noteworthy net effect comes from the traffic increase at airports with air-HSR linkage, and such effect can be stronger for hub airports. Airports without air-HSR linkage experience little traffic change regardless their hub status. This finding is consistent with the international air passenger traffic flow survey conducted by the Ministry of Land, Infrastructure and Transport (MLIT) of Japan in 2012. According to the survey, Narita Airport indeed attracts good amount of international air passenger traffic via Shinkansen, i.e., about 3.5% of its total international air passengers. Fukuoka and Sendai are two representative non-hub airports of which 10.1% and 7.7% of international passengers access the airports via Shinkansen, respectively. Both airports have good air-HSR linkage and Fukuoka's Shinkansen (HSR) station is a major terminal of two Shinkansen lines (Sanyo and Kyushu Shinkansen lines). Sendai is also the hub of the Shinkansen line that goes through the region.

Table 7 Net effects on passenger traffic by air-HSR linkage and hub status (Japan)

HSR	Scenario		Total Passenger		Domestic Passenger		International Passenger	
centrality	AirHSR	Hub	Net effect	Std. Err.	Net effect	Std. Err.	Net effect	Std. Err.
SDgr	0	0	-0.009	0.030	-0.011	0.018	0.002	0.022
	0	1	-0.044	0.039	-0.056**	0.023	0.012	0.029
	1	0	0.166**	0.076	0.038	0.045	0.127**	0.055
	1	1	0.189***	0.071	0.0007	0.042	0.188***	0.052
SHmc	0	0	-0.969	2.475	-0.909	1.466	-0.059	1.817
	0	1	-5.885	4.422	-7.088***	2.619	1.202	3.246
	1	0	11.335**	5.201	2.789	3.081	8.546**	3.818
	1	1	21.467**	8.535	-0.539	5.055	22.01***	6.266

Note: *p < 0.1, ** p < 0.05, ***p < 0.01.

5. Concluding remarks and policy implications

We are the first to quantify HSR's impacts on airport-level traffic by considering the position of an airport city in the HSR network. That is, we believe that the impact of HSR does not rest on its introduction but on the importance of the city in the HSR network. Degree centrality (HSR connectivity) and harmonic centrality (HSR accessibility) are both introduced to measure such importance. The former measures the amount of connections between the airport city and other cities via the HSR system, while the latter measures the closeness of an airport city to all the other cities in terms of HSR travel time. A series of econometric models are estimated by including different HSR centrality measures, air-HSR intermodal linkage, airport hub status and interactions between these variables as key variables of interest. We use two samples of panel data, one for China and one for Japan, to make comparison between these two countries.

Similar to Albalate et al. (2015) and Zhang et al. (2018), in addition to the substitutional effect on airport traffic, we observe a strong complementary feeding effect of HSR on airports allowing for convenient transfer between airport terminals and HSR stations. However, we also find that this feeding effect diminishes in the distance from the airport city to other cities directly reachable by HSR. That is, if HSR mainly connects an airport city with cities located very far away, the catchment of the airport may not be effectively expanded as those living in distance may not perceive air-HSR intermodal service as viable. Thus, even if it is easy to travel between the HSR station and the airport, the amount of feeding traffic will be low. A good air-HSR linkage mainly facilitates HSR to feed international flights and hence increase international traffic at airports. Since airlines in China and Japan face little competition from HSR in international markets, consequently, some airports may experience total traffic increase as HSR connectivity or HSR accessibility increases while others may experience traffic reduction. In particular, hub airports tend to enjoy a higher level of complementary effect from air-HSR intermodal services than non-hub airports, which is consistent with Zhang et al. (2018)'s finding.

We also observe some difference in China and Japan. First, HSR connectivity and accessibility have little impact on domestic air traffic in Japan but they have a strong negative impact on domestic air traffic in China. Consequently, in China, on average, airports with air-HSR linkage experienced much milder air traffic increase than those in Japan. Second, the importance of hub status and air-HSR linkage differs in these two countries. In fact, even without air-HSR linkage, hub airports in China may experience traffic increase though at a lower level than those with air-HSR linkage. This result echoes Albalate et al. (2015)'s finding. However, in contrast to Albalate et al. (2015)'s finding, our results suggest that in China non-hub airports are more negatively affected by HSR even with air-HSR linkage. In a word, HSR development seems to drain traffic from non-hub airports and add traffic to hub airports, exaggerating the uneven traffic distribution among airports, regardless of the availability of air-HSR linkage. In Japan, on the other hand, air-HSR linkage plays a more important role than hub status in terms of adding airport traffic after improving the city’s centrality in the HSR network. Finally, although HSR connectivity and accessibility have similar impacts in Japan, they affect Chinese airports differently. In particular, when air-HSR linkage is available, adding HSR connectivity is more likely to achieve a net traffic increase than improving HSR accessibility in China.

Policy makers may learn several lessons about promoting air-HSR intermodal services from these findings. First, air-HSR intermodal services in many cases may help with feeding traffic to the airport. Therefore, the benefit of congestion mitigation and emission reduction at busy airports may not realize with the help of HSR. In fact, traffic reduction is most likely to occur in small airports which already have too little traffic. In China, hub airports, such as Beijing, Shanghai and Guangzhou, are already very congested. Therefore, to alleviate airport congestion and achieve a better (more even) traffic distribution among large and small airports, it might be a good idea to discourage air-HSR intermodal connection at large, hub airports, while encouraging this investment at small, regional airports. Second, caution should be taken when the policy makers plan to boost their airport traffic by investing in air-HSR intermodal service alone, since small airports with low level of international flight connectivity may risk more severe traffic loss if the air-HSR linkage is added. As shown by Takebayashi (2018), to relieve congestion at large airport by diverting traffic to samller airports using HSR, the key is still to develop local demand for international travel around the smaller airports and build up connectivity to international destinations. This is difficult to achieve by regional airports located in cities with very low income and low growth potential. Thus, investment in intermodal services may not be desirable at these cities. The policy makers may invest air-HSR linkage at airports which have the potential to be converted into international gateway hubs.

Finally, our findings may have implications related to China’s current plan to expand its HSR network into eight west-east corridors and eight north-south corridors. Based on The 2016-2030 Mid-to-Long-Term Railway Network Plan, Xu et al. (2018) projected that enormous new HSR lines will be invested in the low-income, low population-density central/western China by

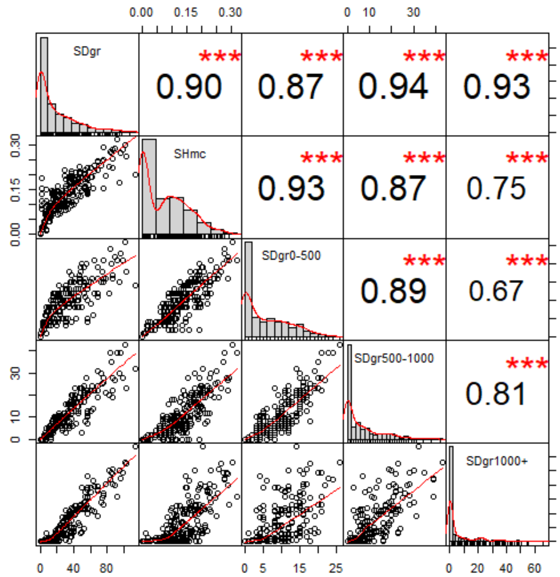
2030. As a result, cities in these regions will expect substantial increase in HSR connectivity and accessibility in the future. Chongqing, Hefei and Chengdu will become the top three based on the connectivity-accessibility index. If this projection is correct, one may expect a much more difficult life for the air transport sector in China in the future, since airports in central/western China are relatively weak and in fact, none of the primary hub airports in China are located in this region. Although the Civil Aviation Administration of China and China Railway Corporation signed an agreement in May 2018 to cooperate in air-HSR intermodal infrastructure development, benefit of promoting air-HSR cooperation in the central/western region is questionable. International air travel demand in the less developed central/western China is quite low but the complementary effect of HSR is the most substantial for international traffic. Moreover, cities like Hefei and Chengdu in central/western China will have very high accessibility but relatively low connectivity by 2030, so very likely the substitution effect of HSR may outweigh the complementary effect. According to Wang et al. (2017), low-density corridors in the central/western China can be much better served by LCCs than HSR due to higher operational flexibility and cost efficiency. Thus, instead of fully executing the 2016-2030 HSR expansion plan, HSR and air transport should take a more coordinated approach to plan for future development of an integrated inter-city transportation system, so that each mode can serve the markets at its best and avoid overinvestment.

Appendix A: List of sample airports, corresponding cities and HSR service commencement years

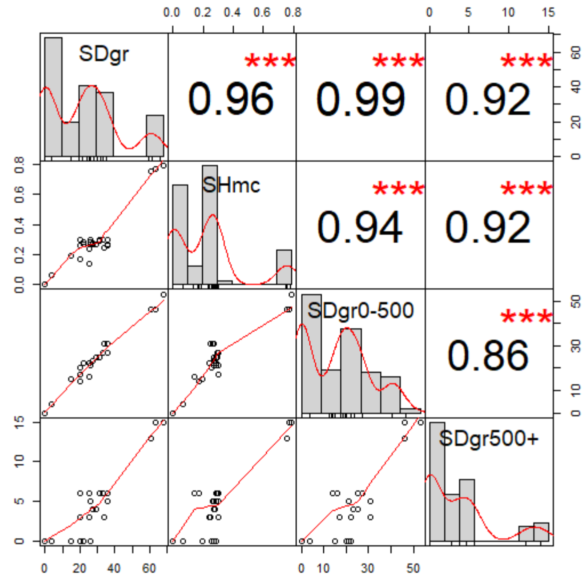
Code	Airport	City	HSR Service	Code	Airport	City	HSR Service
CAN	Guangzhou Baiyun Airport	Guangzhou	2007	CTS	New Chitose Airport	Sapporo	-
CGO	Zhengzhou Xinzheng Airport	Zhengzhou	2007	FUK	Fukuoka Airport	Fukuoka	1975
CGQ	Changchun Longjia Airport	Changchun	2007	HIJ	Hiroshima Airport	Hiroshima	1975
CKG	Chongqing Jiangbei Airport	Chongqing	2010	HND	Haneda Airport	Tokyo	1964
CSX	Changsha Huanghua Airport	Changsha	2007	ITM	Osaka Airport	Osaka	1964
CTU	Chengdu Shuangliu Airport	Chengdu	2010	KIX	Kansai Airport	Osaka	1964
DLC	Dalian Zhoushuizi Airport	Dalian	2013	KMI	Miyazaki Airport	Miyazaki	-
FOC	Fuzhou Changle Airport	Fuzhou	2009	KMJ	Kumamoto Airport	Kumamoto	2011
HAK	Haikou Meilan Airport	Haikou	2011	KMQ	Komatsu Airport	Komatsu	-
HET	Hohhot Baita Airport	Hohhot	2015	KOJ	Kagoshima Airport	Kagoshima	2004
HFE	Hefei Xinqiao Airport	Hefei	2008	MYJ	Matsuyama Airport	Matsuyama	-
HGH	Hangzhou Xiaoshan Airport	Hangzhou	2007	NGO	Chūbu Airport	Nagoya	1964
HRB	Harbin Taiping Airport	Harbin	2007	NGS	Nagasaki Airport	Nagasaki	-
INC	Yinchuan Hedong Airport	Yinchuan	-	NRT	Narita Airport	Tokyo	1964
JHG	Xishuangbanna Gasa Airport	Jinghong	-	SDJ	Sendai Airport	Sendai	1982
JJN	Quanzhou Jinjiang Airport	Quanzhou	2009	UKB	Kobe Airport	Kobe	1972
KHN	Nanchang Changbei Airport	Nanchang	2007				
KMG	Kunming Changshui Airport	Kunming	2016				
KWE	Guilin Liangjiang Airport	Guilin	2014				
KWL	Guiyang Longdongpu Airport	Guiyang	2015				
LJG	Lijiang Sanyi Airport	Lijiang	-				
LXA	Lhasa Gongga Airport	Lhasa	-				
NGB	Ningbo Lishe Airport	Ningbo	2009				
NKG	Nanjing Lukou Airport	Nanjing	2007				
NNG	Nanning Wuxu Airport	Nanning	2014				
PEK	Beijing Capital Airport	Beijing	2007				
SHE	Shenyang Taoxian Airport	Shenyang	2007				
SHPV	Shanghai Pudong Airport Shanghai Hongqiao Airport	Shanghai	2007				
SJW	Shijiazhuang Zhengding Airport	Shijiazhuang	2007				
SWA	Jieyang Chaoshan Airport	Jieyang	2014				
SYX	Sanya Fenghuang Airport	Sanya	2011				
SZX	Shenzhen Baoan Airport	Shenzhen	2007				
TAO	Qingdao Liuting Airport	Qingdao	2007				
TNA	Jinan Yaoqiang Airport	Jinan	2007				
TSN	Tianjin Binhai Airport	Tianjin	2007				
TYN	Taiyuan Wusu Airport	Taiyuan	2009				
URC	Urumqi Diwopu Airport	Urumqi	2015				
WNZ	Wenzhou Longwan Airport	Wenzhou	2009				
WUH	Wuhan Tianhe Airport	Wuhan	2007				
WUX	Sunan Shuofang Airport	Wuxi	2007				
XIY	Xian Xianyang Airport	Xian	2007				
XMN	Xiamen Gaoqi Airport	Xiamen	2009				
XNN	Xining Caojiapu Airport	Xining	2015				
YNT	Yantai Penglai Airport	Yantai	2015				
ZGC	Lanzhou Zhongchuan Airport	Lanzhou	2015				
ZUH	Zhuhai Jinwan Airport	Zhuhai	2011				

Data source: UIC High-speed rail database

Appendix B: Pairwise correlation coefficient between connectivity and accessibility (2007-2015)

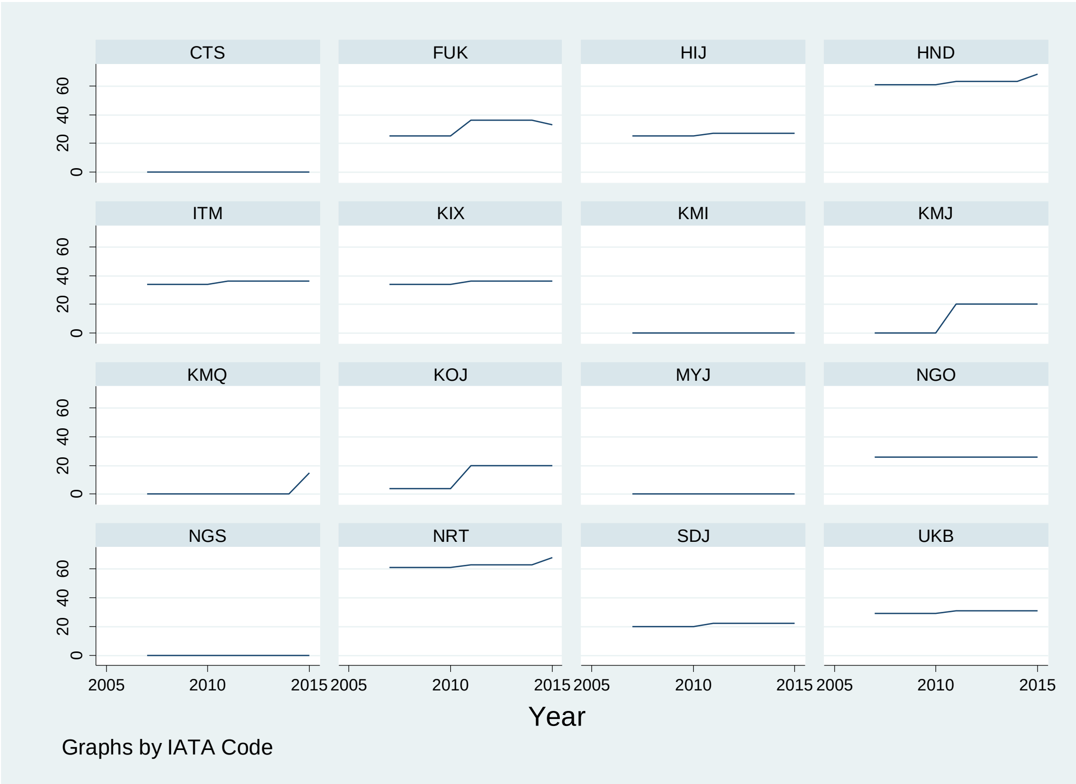


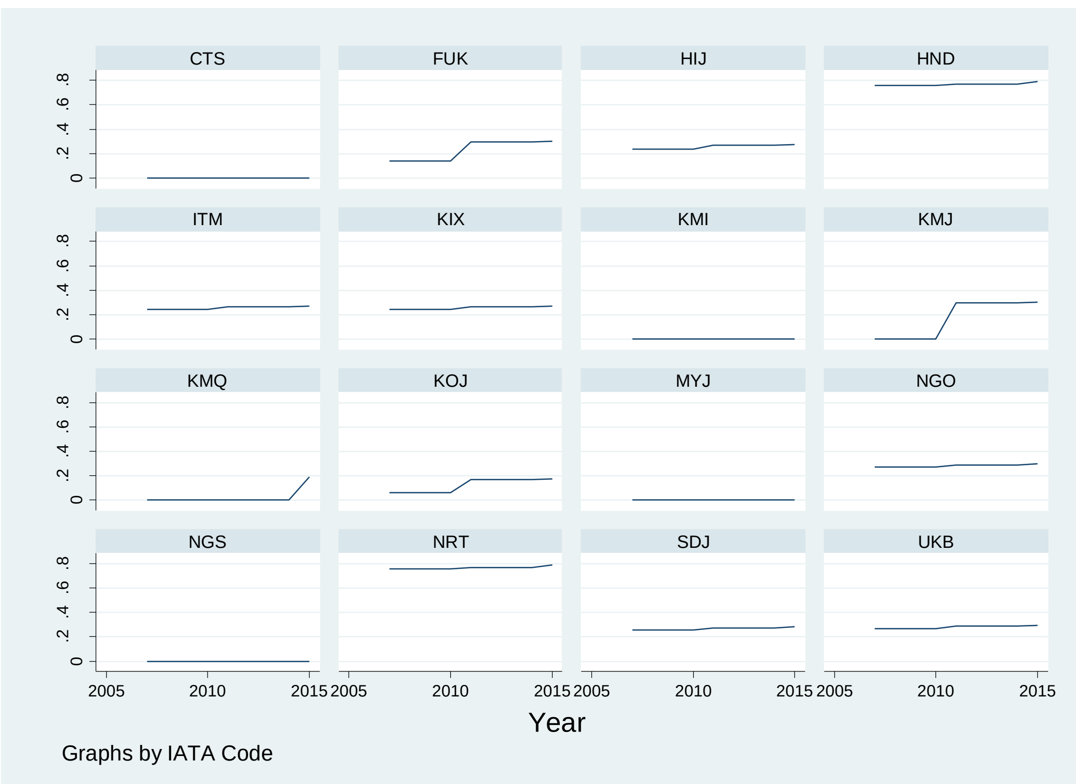
China



Japan

Appendix C: Changes of centrality measures at sampled Japanese airports over 2007-2015





Appendix D: Regression analysis on domestic and international traffic

Table D1 Regression results based on Eq.(3) (DV = domestic passenger traffic, China)

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
HSR zones		0-500	500-1000	1000+			0-500	500-1000	1000+	
POP	3.698***	3.805***	3.785***	3.444***	3.643***	3.591***	3.705***	3.654***	3.390***	3.540***
	(0.280)	(0.262)	(0.267)	(0.278)	(0.269)	(0.277)	(0.263)	(0.269)	(0.275)	(0.268)
GDP_POP	1.888***	2.070***	1.986***	1.626***	1.904***	1.823***	1.982***	1.881***	1.610***	1.819***
	(0.193)	(0.179)	(0.178)	(0.185)	(0.195)	(0.191)	(0.179)	(0.180)	(0.184)	(0.194)
LCC	2.444***	2.294***	2.251***	2.496***	2.449***	2.061***	1.974***	1.987***	2.063***	2.135***
	(0.645)	(0.634)	(0.641)	(0.649)	(0.645)	(0.645)	(0.634)	(0.641)	(0.651)	(0.646)
FuelPrice	-2.314***	-2.286***	-2.345***	-1.554**	-2.153***	-2.123***	-2.177***	-2.135***	-1.516**	-2.051***
	(0.633)	(0.546)	(0.566)	(0.659)	(0.592)	(0.630)	(0.547)	(0.568)	(0.651)	(0.591)
Compete	-4.545***	-5.025***	-4.155***	-4.579***	-4.810***	-4.063***	-4.665***	-3.818***	-4.085***	-4.437***
	(1.104)	(1.086)	(1.096)	(1.111)	(1.108)	(1.096)	(1.082)	(1.093)	(1.103)	(1.102)
Year2008	0.156	0.083	0.146	-0.077	0.043	0.098	0.070	0.093	-0.086	0.033
	(0.398)	(0.377)	(0.383)	(0.406)	(0.387)	(0.394)	(0.375)	(0.381)	(0.401)	(0.384)
Year2009	-0.527	-0.536	-0.514	-0.353	-0.550	-0.430	-0.449	-0.416	-0.296	-0.461
	(0.400)	(0.386)	(0.390)	(0.405)	(0.401)	(0.395)	(0.383)	(0.388)	(0.399)	(0.397)
SDgr	-0.021**	-0.222***	-0.102***	0.001		-0.025**	-0.217***	-0.095***	-0.014	
	(0.010)	(0.050)	(0.027)	(0.016)		(0.010)	(0.049)	(0.027)	(0.017)	
SHmc					-7.696**					-7.605**
					(3.467)					(3.456)
AirHSR						1.128	2.005**	1.340*	1.075	2.004**
						(0.784)	(0.872)	(0.747)	(0.717)	(0.890)
SDgr × AirHSR						0.017	-0.036	0.022	0.038	
						(0.015)	(0.079)	(0.054)	(0.025)	
SHmc × AirHSR										-1.967
										(5.615)
Constant	-19.58***	-20.05***	-20.60***	-17.72***	-19.05***	-19.02***	-19.38***	-19.72***	-17.58***	-18.36***
	(1.893)	(1.740)	(1.841)	(1.863)	(1.790)	(1.875)	(1.738)	(1.848)	(1.847)	(1.781)
N	414	414	414	414	414	414	414	414	414	414
R^2	0.438	0.436	0.446	0.432	0.436	0.446	0.440	0.451	0.442	0.442

Note: Standard errors are in parentheses. Airport dummies are omitted to save space. *p < 0.1, ** p < 0.05, ***p < 0.01.

Table D2 Regression results based on Eq.(3) (DV = international passenger traffic, China)

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
HSR zones		0-500	500-1000	1000+			0-500	500-1000	1000+	
POP	1.377***	1.495***	1.516***	1.258***	1.423***	1.270***	1.328***	1.367***	1.229***	1.294***
	(0.130)	(0.124)	(0.125)	(0.127)	(0.126)	(0.116)	(0.113)	(0.117)	(0.113)	(0.111)
GDP_POP	0.084	0.221**	0.230***	-0.028	0.131	0.050	0.121	0.140*	-0.003	0.068
	(0.090)	(0.085)	(0.083)	(0.084)	(0.091)	(0.080)	(0.077)	(0.078)	(0.076)	(0.081)
LCC	0.023	-0.027	-0.054	-0.010	0.013	-0.379	-0.218	-0.270	-0.491*	-0.375
	(0.301)	(0.301)	(0.301)	(0.297)	(0.301)	(0.269)	(0.273)	(0.281)	(0.269)	(0.269)
FuelPrice	-0.620**	-0.903***	-0.971***	-0.169	-0.756***	-0.270	-0.553**	-0.653***	-0.044	-0.388
	(0.295)	(0.259)	(0.266)	(0.301)	(0.277)	(0.263)	(0.235)	(0.248)	(0.269)	(0.246)
Compete	-1.666***	-1.749***	-1.542***	-1.644***	-1.657***	-1.114**	-1.267***	-1.112**	-1.124**	-1.193**
	(0.515)	(0.515)	(0.515)	(0.508)	(0.518)	(0.458)	(0.466)	(0.478)	(0.455)	(0.459)
Year2008	0.299	0.373**	0.401**	0.149	0.341**	0.161	0.248	0.293*	0.088	0.177
	(0.185)	(0.179)	(0.180)	(0.185)	(0.181)	(0.164)	(0.161)	(0.167)	(0.165)	(0.160)
Year2009	-0.191	-0.259	-0.266	-0.084	-0.222	-0.088	-0.148	-0.160	-0.036	-0.133
	(0.186)	(0.183)	(0.183)	(0.185)	(0.187)	(0.165)	(0.165)	(0.169)	(0.165)	(0.165)
SDgr	0.004	-0.045*	-0.028**	0.025***		-0.003	-0.044**	-0.028**	0.002	
	(0.004)	(0.023)	(0.013)	(0.007)		(0.004)	(0.021)	(0.012)	(0.007)	
SHmc					0.054					-1.556
					(1.621)					(1.441)
AirHSR						-0.497	-0.697*	0.145	-0.166	-0.957**
						(0.327)	(0.376)	(0.327)	(0.296)	(0.371)
SDgr × AirHSR						0.051***	0.242***	0.130***	0.083***	
						(0.006)	(0.034)	(0.023)	(0.010)	
SHmc × AirHSR										18.871***
										(2.341)
Constant	-7.48***	-8.28***	-8.60***	-6.67***	-7.81***	-7.15***	-7.33***	-7.76***	-6.90***	-7.18
	(0.884)	(0.826)	(0.865)	(0.852)	(0.837)	(0.783)	(0.749)	(0.809)	(0.763)	(0.742)
N	414	414	414	414	414	414	414	414	414	414
R^2	0.310	0.314	0.321	0.304	0.313	0.346	0.347	0.346	0.338	0.344

Note: Standard errors are in parentheses. Airport dummies are omitted to save space. *p < 0.1, ** p < 0.05, ***p < 0.01.

Table D3 Regression results based on Eq.(3) (DV = domestic passenger traffic, Japan)

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
HSR zones		0-500	500+			0-500	500+	
POP	5.095***	5.053***	5.394***	5.078***	4.359***	4.383***	5.127***	4.271***
	(1.313)	(1.320)	(1.295)	(1.312)	(1.339)	(1.332)	(1.414)	(1.359)
GDP_POP	1.527**	1.481**	1.783***	1.526**	1.348**	1.348**	1.721***	1.359**
	(0.595)	(0.596)	(0.592)	(0.597)	(0.594)	(0.590)	(0.643)	(0.597)
LCC	0.892***	0.884***	0.957***	0.887***	0.999***	0.986***	1.072***	1.084***
	(0.211)	(0.211)	(0.209)	(0.211)	(0.238)	(0.235)	(0.230)	(0.231)
FuelPrice	-0.568*	-0.570*	-0.456	-0.570*	-0.573*	-0.546	-0.454	-0.563*
	(0.336)	(0.336)	(0.333)	(0.336)	(0.332)	(0.331)	(0.338)	(0.332)
Compete	-4.357***	-4.366***	-4.243***	-4.363***	-5.099***	-4.711***	-3.264**	-5.168***
	(0.683)	(0.684)	(0.673)	(0.683)	(1.578)	(1.183)	(1.549)	(1.824)
Year2009	-0.602**	-0.595**	-0.586**	-0.600**	-0.610**	-0.589**	-0.581**	-0.606**
	(0.279)	(0.279)	(0.273)	(0.278)	(0.275)	(0.275)	(0.276)	(0.275)
Year2011	-0.973	-0.987**	-0.906***	-0.976**	-0.947***	-0.955***	-0.883***	-0.934***
	(0.217)	(0.217)	(0.214)	(0.217)	(0.217)	(0.216)	(0.216)	(0.216)
SDgr	-0.008	0.0004	-0.129**		-0.015	-0.014	-0.095	
	(0.017)	(0.020)	(0.058)		(0.018)	(0.022)	(0.069)	
SHmc				-0.549				-1.109
				(1.387)				(1.502)
AirHSR					-2.400*	-2.400**	-0.386	-1.776*
					(1.364)	(1.145)	(0.651)	(1.029)
SDgr×AirHSR					0.053	0.062	-0.038	
					(0.042)	(0.041)	(0.131)	
SHmc×AirHSR								3.665
								(3.444)
Constant	-18.62**	-18.38**	-21.21**	-18.57**	-13.14	-13.70	-20.50**	-12.86
	(7.627)	(7.656)	(7.576)	(7.627)	(8.065)	(7.807)	(8.998)	(8.316)
N	144	144	144	144	144	144	144	144
R^2	0.365	0.365	0.365	0.365	0.368	0.370	0.374	0.369

Note: Standard errors are in parentheses. Airport dummies are omitted to save space. *p <0.1, ** p<0.05, ***p<0.01.

Table D4 Regression results based on Eq.(3) (DV = international passenger traffic, Japan)

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
HSR zones		0-500	500+			0-500	500+	
POP	-1.604	-1.748	-1.500	-1.562	-1.930	-1.839	-0.882	-1.780
	(1.639)	(1.640)	(1.654)	(1.639)	(1.620)	(1.585)	(1.802)	(1.693)
GDP_POP	0.676	0.629	0.793	0.677	0.523	0.616	0.991	0.649
	(0.743)	(0.740)	(0.756)	(0.746)	(0.718)	(0.701)	(0.819)	(0.744)
LCC	0.631**	0.644**	0.652**	0.642	0.234	0.237	0.490*	0.523*
	(0.264)	(0.262)	(0.267)	(0.263)	(0.287)	(0.280)	(0.293)	(0.288)
FuelPrice	-0.821*	-0.789*	-0.810*	-0.815*	-0.901**	-0.771*	-0.791*	-0.846**
	(0.419)	(0.418)	(0.426)	(0.419)	(0.402)	(0.394)	(0.430)	(0.414)
Compete	6.795***	6.849***	6.821***	6.810***	0.586	2.163	5.944***	2.340
	(0.853)	(0.850)	(0.859)	(0.854)	(1.908)	(1.408)	(1.975)	(2.273)
Year2009	-0.299	-0.286	-0.315	-0.304	-0.297	-0.239	-0.305	-0.299
	(0.348)	(0.347)	(0.349)	(0.348)	(0.333)	(0.327)	(0.352)	(0.343)
Year2011	-0.363	-0.370	-0.328	-0.357	-0.486*	-0.477*	-0.355	-0.414
	(0.271)	(0.269)	(0.274)	(0.271)	(0.263)	(0.257)	(0.275)	(0.270)
SDgr	0.020	0.035	-0.002		-0.002	-0.007	-0.038	
	(0.021)	(0.026)	(0.075)		(0.022)	(0.026)	(0.088)	
SHmc				1.454				0.005
				(1.733)				(1.872)
AirHSR					-4.522***	-4.169***	0.812	-1.431
					(1.650)	(1.363)	(0.830)	(1.283)
SDgr×AirHSR					0.171***	0.190***	-0.003	
					(0.051)	(0.049)	(0.167)	
SHmc×AirHSR								7.791*
								(4.293)
Constant	2.14	2.82	1.53	2.03	10.64	8.34	-1.66	7.43
	(9.521)	(9.512)	(9.675)	(9.526)	(9.754)	(9.287)	(11.467)	(10.365)
N	144	144	144	144	144	144	144	144
R^2	0.285	0.342	0.266	0.274	0.355	0.425	0.472	0.443

Note: Standard errors are in parentheses. Airport dummies are omitted to save space. *p <0.1, ** p<0.05, ***p<0.01.

Appendix E: Regression analysis with airport hub status

Table E1 Regression results based on Eq.(4) (China)

	Total		Domestic		International	
	(1)	(2)	(3)	(4)	(5)	(6)
POP	3.764***	3.983***	3.170***	3.202***	0.593***	0.780***
	(0.335)	(0.326)	(0.299)	(0.288)	(0.075)	(0.067)
GDP_POP	1.940***	1.987***	1.835***	1.852***	0.105**	0.134***
	(0.215)	(0.222)	(0.191)	(0.196)	(0.048)	(0.046)
LCC	2.302***	2.349***	2.262***	2.433***	0.039	-0.084
	(0.727)	(0.738)	(0.649)	(0.653)	(0.163)	(0.153)
FuelPrice	-2.356***	-2.568***	-2.066***	-2.137***	-0.289*	-0.430***
	(0.700)	(0.673)	(0.624)	(0.595)	(0.157)	(0.139)
Compete	-3.953***	-4.624***	-3.546***	-4.022***	-0.407	-0.601**
	(1.231)	(1.249)	(1.098)	(1.105)	(0.276)	(0.259)
Year2008	0.106	0.157	0.020	0.025	0.085	0.131
	(0.438)	(0.434)	(0.391)	(0.384)	(0.098)	(0.090)
Year2009	-0.597	-0.648	-0.462	-0.500	-0.134	-0.148
	(0.437)	(0.445)	(0.390)	(0.394)	(0.098)	(0.092)
SDgr	-0.023**		-0.023**		0.0007	
	(0.011)		(0.010)		(0.002)	
SHmc		-8.666**		-7.393**		-1.273
		(3.863)		(3.417)		(0.802)
AirHSR	1.640*	2.199**	1.662*	2.246**	-0.021	-0.046
	(0.962)	(1.047)	(0.858)	(0.926)	(0.216)	(0.217)
Hub	-1.192	-1.881	-0.041	-0.164	-1.151***	-1.717***
	(1.926)	(2.235)	(1.718)	(1.977)	(0.432)	(0.464)
SDgr × AirHSR	-0.007		-0.011		0.004	
	(0.020)		(0.018)		(0.004)	
SDgr × Hub	0.075***		0.033*		0.041***	
	(0.020)		(0.018)		(0.004)	
SHmc × AirHSR		-8.901		-10.36*		1.462
		(7.005)		(6.197)		(1.455)
SHmc × Hub		21.282*		8.861		12.421***
		(11.017)		(9.746)		(2.288)
AirHSR × Hub	2.292	-2.547	0.033	1.100	2.258***	-3.647***
	(2.258)	(3.456)	(2.014)	(3.057)	(0.507)	(0.717)
SDgr × AirHSR × Hub	0.116***		0.048		0.067***	
	(0.039)		(0.035)		(0.008)	
SHmc × AirHSR × Hub		64.122***		12.628		51.494***
		(20.443)		(18.085)		(4.246)
Constant	-19.39***	-20.28***	-16.46***	-16.27***	-2.931***	-4.01***
	(2.231)	(2.1517)	(1.990)	(1.903)	(0.501)	(0.446)
N	414	414	414	414	414	414
R^2	0.502	0.482	0.476	0.467	0.555	0.465

Note: Standard errors are in parentheses. Airport dummies are omitted to save space. *p <0.1, ** p<0.05, ***p<0.01.

Table E2 Regression results based on Eq.(4) (Japan)

	Total		Domestic		International	
	(1)	(2)	(3)	(4)	(5)	(6)
POP	3.438	3.975*	4.670***	4.652***	-1.232	-0.676
	(2.313)	(2.296)	(1.374)	(1.360)	(1.694)	(1.685)
GDP_POP	1.891*	1.951**	1.277**	1.280**	0.614	0.671
	(0.982)	(0.984)	(0.583)	(0.583)	(0.719)	(0.722)
LCC	1.033**	1.078**	1.004***	1.016***	0.028	0.062
	(0.431)	(0.432)	(0.256)	(0.256)	(0.316)	(0.317)
FuelPrice	-1.475***	-1.449***	-0.597**	-0.588*	-0.878**	-0.861**
	(0.548)	(0.548)	(0.325)	(0.324)	(0.401)	(0.402)
Compete	-5.838**	-13.408***	-5.331***	-7.111**	-0.507	-6.296*
	(2.791)	(4.912)	(1.657)	(2.909)	(2.043)	(3.606)
Year2009	-0.886*	-0.871*	-0.608**	-0.602**	-0.277	-0.269
	(0.454)	(0.454)	(0.269)	(0.269)	(0.332)	(0.333)
Year2011	-1.431***	-1.412***	-0.917***	-0.916***	-0.514*	-0.496*
	(0.359)	(0.359)	(0.213)	(0.212)	(0.263)	(0.263)
SDgr	-0.009		-0.011		0.002	
	(0.030)		(0.018)		(0.022)	
SHmc		-0.969		-0.909		-0.059
		(2.475)		(1.466)		(1.817)
AirHSR	-6.403***	-5.307***	-2.419*	-2.114*	-3.984**	-3.192**
	(2.297)	(1.868)	(0.016)	(1.107)	(1.682)	(1.372)
Hub	(omitted)					
SDgr × AirHSR	0.176**		0.050		0.125**	
	(0.081)		(0.048)		(0.059)	
SDgr × Hub	-0.034		-0.044***		0.009	
	(0.027)		(0.016)		(0.020)	
SHmc × AirHSR		12.305**		3.699		8.605**
		(5.681)		(3.365)		(4.171)
SHmc × Hub		-4.916		-6.178***		1.262
		(3.792)		(2.246)		(2.783)
AirHSR × Hub	(omitted)					
SDgr × AirHSR × Hub	0.057		0.006		0.051	
	(0.046)		(0.027)		(0.033)	
SHmc × AirHSR × Hub		15.047***		2.849		12.197***
		(5.503)		(3.259)		(4.040)
Constant	-6.03	-2.12	-13.74*	-11.91	7.71	9.78
	(13.562)	(13.737)	(8.055)	(8.137)	(9.931)	(10.085)
N	144	144	144	144	144	144
R^2	0.724	0.583	0.364	0.344		

Note: Standard errors are in parentheses. Airport dummies are omitted to save space. *p <0.1, ** p<0.05, ***p<0.01.

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