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# Impacts of High-speed Rail on Airlines, Airports and Regional Economies: A Survey of Recent Research

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**Abstract:** This paper first reviews studies on the impacts of air-HSR competition on airlines, focusing on the overall effects of parallel HSR services on passengers' mode choice as well as on airlines' flight frequency, traffic volume, fares, service quality and market power. The modal complementarity and air-HSR intermodal services, together with the network feature of airline business, are also examined. The paper then reviews theoretical and empirical findings on the impacts of HSR on airports and regional economies. Here, the main insights include: First, HSR can have a traffic redistribution effect on airport traffic; in particular, some primary hub airports with good air connectivity may gain traffic while others may lose traffic. Second, to mitigate congestion at hub airports, policy makers may consider diverting some traffic to regional airports by promoting air-HSR intermodal services. Third, as HSR may stimulate long-haul / international air traffic, its overall impact on emission reduction remains unclear. Finally, similar to the impacts on airport traffic, spatial disparity of economic activities may also rise after the introduction of HSR. In general, the disparity tends to rise between the cities with HSR and those without HSR, as the former gets better accessibility. However, among the cities with HSR services, the disparity between the large and small cities could increase or decrease depending on several factors.

**Keywords:** High-speed rail; Airline; Airport traffic; Traffic redistribution; Regional economy; Siphon effect

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## 1. Introduction

In July 2016, China announced a new "Mid-and-Long Term Railway Network Plan" (MLTRNP), indicating that its high-speed rail (HSR) track length would reach 38,000 km by 2025. The 38,000 km tracks will double the length in operation (19,000 km) in 2015 and include eight north-south and eight east-west trunk lines (so-called the "8+8" network), which represents a major extension of the current "4+4" network. As part of the MLTRNP, 192 cities of prefectural-level would be connected by HSR lines by 2020 (Fu et al., 2015). According to the latest report by the International Union of Railways, the total length of HSR tracks in operation in China is 27,684 km, which is 64% of the world's total, 42,978 km (UIC, 2018). This is impressive especially given that the first major HSR line in China started operation only in August 2008.

Apart from China, HSR developments are taking place, or are planned, in a number of other countries, and the world HSR network is expected to more than double the 2014 length by 2025 (Givoni and Dobruszkes, 2013; Xia and Zhang, 2016; UIC, 2018). This wave of developments is a continuation of decades-long HSR developments around the world.[1] The HSR technology has been seen as a central policy element in transportation and regional development. The policy objectives include: (i) to improve people's mobility through accessing inter-city transportation; (ii) to reduce the negative environmental impact of transportation; (iii) to stimulate regional economic growth; and (iv) to improve spatial distribution of traffic and economic developments across regions (e.g., European Commission, 2011; MLTRNP, 2016; Wu and Huang, 2019). There is a substantial body of literature on assessing whether and to what extent these policy objectives are achieved in practice. The present paper offers an interpretative review of this literature, based primarily on the interactions between HSR and air transportation. Our literature review will focus on the empirical findings and policy implications, although some discussion will extend to research methodologies as well. We note that the assessment of policy outcomes is particularly important to policy making given the on-going HSR developments in China and

[1] The first modern HSR – the route between Tokyo and Osaka with a maximum speed of 210 km/hour – went into operation in Japan in October 1964 (Givoni, 2006). In 1976, British Railways opened an HSR line between London and Bristol. France commenced the operation of its first HSR between Paris and Lyon in 1981. Since then, many European countries have built HSR lines, including Spain, Germany, Italy, Belgium, and the Netherlands. In Asia, Japan remained as the only economy operating HSR service until this century, when several economies in East Asia started HSR services. South Korea started its first HSR line between Seoul and Daegu in 2004 (which was, in 2009, extended to Busan), and Taiwan started its HSR service between Taipei and Kaohsiung in 2007.

elsewhere and huge amount of public funds involved. For instance, China's total HSR investment from 2017 to 2025 is estimated to be about 7.2 trillion RMB (1.04 trillion USD), which is about 10% of Chinese GDP in 2016 (Wang et al., 2017). Meanwhile, based on the financial reports of China Railway Corporation (the former Ministry of Railways), its debt has increased from 1.89 trillion RMB (274 billion USD) at the end of 2010 to 5.28 trillion RMB (765 billion USD) by the end of September 2018.[2] These significant financial costs must be evaluated against the intended benefits. The need for a literature review paper also arises due to the fact that a large number of papers have been published over the last five years and it is time to summarize and interpret the main results emanating from this body of knowledge.

We shall focus on summarizing and interpreting recent studies that examine the impacts of HSR on airlines, airports and regional economies. For example, it is hoped under objective (iv) that HSR would shift some air traffic away from a (congested) hub airport to nearby (under-utilized) smaller airports so that these airports as a group, as well as their respective cities/regions, can have a more balanced growth. More specifically, a major impact of HSR development is on air transportation: as elaborated below, both modes are competitors for inter-city passengers of a fairly large distance range. In fact, under China's recent expansion plan, by 2025 about 80% of its domestic airline routes will overlap with HSR lines. In this paper, we first review the impacts of the air-HSR competition on airlines. The focus is on the overall effects of parallel HSR services on passengers' mode choice as well as on airlines' traffic volumes, fares, flight frequencies and service quality. Apart from the competition aspect, HSR can complement air transport with air-HSR intermodal services. This, together with the network feature of airline business, would substantially complicate the interactions between HSR and air transportation. In effect, in some recent studies air traffic *increase* was observed on certain routes which questions, for example, the effectiveness of using HSR as a policy device to mitigate airport congestion and emissions.

The above observation motivates the second part of our survey: this part summarizes and interprets theoretical and empirical findings on the impacts of HSR on airports and regional

[2] See the article "With debt 5.28 trillion RMB, is high-speed rail a major financial risk for Chinese economy?" (in Chinese), available at https://news.sina.com.cn/c/2019-04-28/doc-ihvhiewr8641875.shtml. In 2010, the total railway investment amounted to 842 billion RMB (122 billion USD) (Zhao et al. 2015). From 2011 to 2015, the period in which China's 12th Five-Year Plan was implemented, the fixed-asset investment in railways amounted to 3.58 trillion RMB (520 billion USD), with a yearly average of 716 billion RMB (103 billion USD). In 2016, the total railway investment was estimated to be above 800 billion RMB (115 billion USD).

economies. The main insights from our extensive review are as follows. First, HSR can have a traffic redistribution effect on airport traffic: in particular, some primary hub airports with good air connectivity may gain traffic while smaller spoke airports may lose traffic, thus worsening the cost recovery for the small airports. This distributional inequality may be caused by unequal improvements in accessibility to non-local markets or increased competition between rival airports after the introduction of HSR. Second, to mitigate congestion at primary hub airports, policy makers can consider diverting some traffic to regional airports by promoting air-HSR intermodal services. However, in addition to physical connection between airport and HSR station, appropriate plans to either attract international business activities or convert the airport into an airline's hub need to be provided. Here, policy makers can play an important role in ensuring sufficient investments on the intermodal service. Third, as HSR may stimulate long-haul/international air traffic, its overall impacts on hub airport congestion and on emission reduction remains unclear. Finally, similar to the impacts on airport traffic, spatial disparity of economic activities may also rise after the introduction of HSR. In general, the disparity tends to rise between the cities with HSR and those without HSR, as the former gets better accessiblity. However, among the cities with HSR services, the disparity between the large and small cities could increase or decrease depending on several factors. In other words, the "siphon effect" – that is, large cites attracting activities away from small cities – may occur under certain situations.

The present survey is a natural sequel of earlier survey papers by, for example, Givoni and Dobruszkes (2013), Sun et al. (2017), Yang et al. (2018), and Xia et al. (2018), especially concerning various aspects of the competition between HSR and air transportation. What distinguishes our paper are: First, we have the obvious opportunity to include more recent material than is discussed in the earlier surveys, especially the recent and rapidly expanding literature on Chinese and Asian experiences. This allows us to include recent work on the effects of HSR speed on air transportation, the effects of HSR on airline service and market power, and the effects of air-HSR cooperation, leading to a more complete guide to the literature on HSR-air interactions. For example, the recent results that the elasticities of airline (equilibrium) traffic and price with respect to HSR speed are larger in magnitude on short-haul routes (vs. long-haul routes) and at higher HSR speed have important managerial and policy implications for evaluating China's HSR expansion program as well as on-going projects in other countries, for the new HSR technology exhibits higher speed. Second, the present paper further offers, to our best knowledge, the first comprehensive review of the impacts of HSR on airports and regional economies. As noted above, the results here will have important implications that are relevant for policy making. We further discuss avenues for future research on the topics.

The paper is organized as follows. Section 2 provides a review on the route-level impact of air-HSR competition on airlines' traffic, fares, frequency and service quality, and on air-HSR cooperation and intermodal services. Section 3 discusses the impact of HSR on airport traffic. By reviewing theoretical and empirical studies that take into account both the substitution and complementary effects of HSR, this section summarizes three mechanisms through which HSR developments may lead to an increase in disparity of airport traffic distribution. Section 4 analyzes how the HSR effect on airport traffic might be relevant to policies that aim at reducing airport congestion and greenhouse gas emissions. Section 5 extends the idea of airport traffic redistribution to regional economic activities and summarizes findings from the relevant literatures. Finally, Section 6 contains concluding remarks and a discussion on avenues for future studies.

## 2. Impact on Airlines

### 2.1 Effects of air-HSR competition

The earlier stream of the theoretical literature on air-HSR interactions focuses on the competition between airlines and HSR. Here, studies have examined both the short- and long-term effects of HSR on airfares, profits, and social welfare (e.g., Adler et al., 2010; Yang and Zhang, 2012; Dobruszkes et al., 2014; Jiang and Zhang, 2016; Tsunoda, 2018). Adler et al. (2010) adopted a nested multinomial logit model to analyze competition between the two modes in a medium- to long-distance rail network, which includes all the 27 EU countries and 71 zones. However, they were unable to obtain the analytical solutions and instead solved the model using a European case study. The authors concluded that the EU should encourage the development of the HSR network across Europe. Based on an analytical model, Yang and Zhang (2012) showed, among others, that the airfare tends to fall, whilst the rail fare tends to rise, if the access time to an airport is longer. Airfare is negatively related to rail speed if the marginal cost of HSR with respect to rail speed is not too large. The authors further conducted a numerical analysis to verify their analytical results. Using a pure analytical model, Jiang and Zhang (2016) shed light on the long-term impact to airlines brought about by HSR. They showed that HSR competition may induce airlines to change their network structure from point-to-point to hub-and-spoke and to cover more fringe markets.[3] Furthermore, this long-term response by airlines can be a source of social welfare gain.

There is a vast empirical literature on the effects of HSR on parallel airline services. A large group of empirical studies focus on passengers' willingness-to-pay and their terminal accessibility and modal choice behavior. For example, in the Madrid–Barcelona market: González-Savignat (2004) found that impacts on airlines depend on HSR travel time; and Roman et al. (2007), based on a mixed set of revealed-preference and stated-preference data, obtained willingness-to-pay measures for service quality improvements. Martin et al. (2014) examined the effect of access and egress times to transport terminals on the spatial modal distribution in the Madrid-Barcelona corridor. They extended the previous literature[4] by presenting a detailed spatial analysis of accessibility to terminals, as this is not as simple as just the journey time from the city center of Madrid or Barcelona. The authors showed that easy access by private car tends to favor the relative competitiveness of air transport, whilst easy public transport access tends to improve HSR competitiveness. Behrens and Pels (2012) studied the travelers' behavior in the London-Paris market and found that HSR's frequency and travel time were the main determinants of travel behavior. Martin and Nombela (2007) showed that in Spain, HSR trains would attract travelers from planes and buses on the long-haul routes, while on the short-haul routes trains would mainly attract car users.

Another group of empirical papers examine airlines' behavior with route-level data. Most of these studies have found that competition from HSR has exerted a downward pressure on airfares, flight frequencies, and air traffic (e.g., Wardman et al., 2002; Campos and de Rus, 2009; Albalate and Bel, 2012; Givoni and Dobruszkes, 2013; Dobruszkes et al., 2014; Albalate et al., 2015; Wan et al., 2016; Chen, 2017; Wang et al., 2018). Here, the largest stream deals with European data. By taking a supply-oriented analysis, Albalate et al. (2015) found that airlines reduced the number of seats offered when facing competition from HSR but not the frequency. Jiménez and Betancor (2012) found that the HSR entry has, on average, led to a reduction in the number of air operations by 17% in Spain. The previous literature has confirmed that HSR frequency and the number of HSR seats are important factors affecting the outcome of air-HSR

[3] See Dobruszkes et al. (2014) for an empirical analysis on the HSR effect when airlines adopt hubbing strategies. The result is consistent with that of Jiang and Zhang (2016).

[4] For example, Chang and Lee (2008) proposed a reduced form of a Hansen-type accessibility measure and conducted a systemized accessibility analysis of the HSR station in the Seoul metropolitan area.

competition (Castillo-Manzano et al., 2015; Jiménez and Betancor, 2012). Both Castillo-Manzano et al. (2015) and Jimenez and Betancor (2012) found that air demand is negatively associated with the number of HSR seats.

The second stream of this literature focuses on the Chinese market, which is understandable given the astonishing developments recently occurred there (e.g., Fu et al., 2012; Givoni et al., 2012). The spread of HSR network has forced Chinese airlines to slash domestic airfares and reduce or cancel flights. For instance, all the flights between Zhengzhou and Xi'an (the route distance is 505 km) were cancelled by the airlines in March 2010 — 48 days after the opening of HSR service — due to very low demand. Even for the Wuhan-Guangzhou route — a much longer route (1,069 km) — daily airline flights were reduced from 15 to 9, one year after the HSR entry (Fu et al., 2012). Chen (2017) investigated the air-HSR competition on the Wuhan-Guangzhou and Beijing-Shanghai routes and found a significant drop in air traffic, flight frequency and seat capacity after the introduction of parallel HSR services. In particular, air travel declined by approximately 45% after commencement of the Wuhan-Guangzhou HSR, and it fell by 34% after the opening of the Beijing-Shanghai HSR. Zhang et al. (2019) found, using a panel dataset of 30 different routes in China, that the HSR competition reduced airfares by 34% and flight frequencies by 60%. Using a panel dataset from 2007 to 2013 for 138 routes with HSR-air competition, Yang et al. (2018) found that the entry of new HSR services in general leads to a 27% reduction in air travel demand, while Li et al. (2019a) suggested a 50% reduction. Li et al. (2019b) further identified a strong negative impact of HSR frequency on air travel demand. They also noted that the negative impact of HSR is strong in China's central and western regions. Fang et al. (2019) analyzed the effects of HSR competition on airlines' quality by utilizing a unique dataset containing all flights departing from Beijing to 113 domestic destinations in China from January 2009 to December 2012. They found that the HSR entry introduces competition to the airline industry, facilitating improvements in the productivity or on-time performance of affected flights, and that the decrease in departure delay is identified as the source of the increase in productivity. Finally, Wang et al. (2017) analyzed whether China should further expand its HSR network by considering the role of low-cost carriers (LCCs) and regional airlines as an alternative transport mode.[5] The authors called for a more careful evaluation of the program and, more generally, a balanced and coordinated HSR and LCC development in China.

Besides the extensive literature on the European and Chinese markets, there are studies on other regions as well. For example, the opening of Shinkansen in Japan reduced air passenger traffic significantly, and the introduction of Korean Train Express (KTX) in 2004 affected both passenger demand and airfare (e.g., Vickerman, 1997; Suh et al., 2005; Chang and Lee, 2008). Using the stated-preference survey method, Park and Ha (2006) showed that the opening of KTX imposed significant competitive pressures on airlines in South Korea's domestic market. Wan et al. (2016) investigated the effects of HSR on airlines in China, Japan, and South Korea. The authors found that the entry of HSR had a strong, negative impact on short-haul and medium-haul air routes seat capacity in both China and Japan. Jiang and Li (2016) compared the LCC and HSR sectors between Japan and Western Europe. The authors found that both regions had strong HSR systems, but the development of Japanese LCCs lagged behind that of its European counterparts.

In sum, almost all studies found that the entry of HSR has negative impacts on airlines, e.g., reductions in air traffic, fare, and flight frequency. Furthermore, in the Chinese market, HSR affects not only short- to medium-distance routes, but also long-distance (more than 900 km) routes such as the Wuhan-Guangzhou route (1,069 km) and the Beijing-Shanghai route (1,318 km) (Fu et al., 2012; Zhang and Zhang, 2016; Chen, 2017). This is in contrast to the result that HSR has little effect on long-distance routes in European and other markets (Adler et al., 2010; Rothengatter, 2011; Albalate et al., 2015).[6] This may be related to the fact that China has developed a comprehensive network with convenient transfers at several "hub" stations, a faster (average) train speed, as well as an integrated domestic market with strong ridership especially in Eastern China. The strong ridership allows for frequent origin-destination (OD) services, further stimulating

[5] In particular, their analysis suggested that while in the highly populated and developed corridors the HSR expansion is likely to leave LCCs with little survival room, LCCs and regional airlines may leave HSR with little survival room in the low-density corridors especially in the central and western China (Hu et al., 2019). In other words, for the routes to the central and western China with very small travel demand and high HSR construction cost, LCC service could be more cost efficient and operationally flexible than HSR. Wang et al.'s analysis called for a more careful evaluation of the program. For a more general analysis of the expansion program, see Xu and Huang (2019).

[6] It is found that in Europe HSR dominates the market for journeys of 2 hours or less, such as between Paris and Brussels, but that air travel dominates the market for journeys longer than 5 to 6 hours (HSR has only a tiny market share).

ridership.[7] A weaker LCC/regional airline sector, as compared to those in Europe and East Asia, also contributes to the different results (Wang et al., 2017).

## 2.2 Effects of HSR speed

As mentioned above, train speed plays a key role in the extent of air-HSR competition: The two services used to be unrelated in that the air mode was for medium-to-long distance travel while rail, with a much slower speed, for short distance travel. As a result of "high speed" rail, the two modes become effective competitors over a much longer range of distance.[8]

Most studies found that the HSR is a strong competitor of air transport on short- and medium-distance routes (Gonzalez-Savignat, 2004; Givoni and Banister, 2006; Hu et al., 2015). HSR is found to be the dominant transport mode for travel distance between 300 km to 700 km (Fu et al., 2014; Román et al., 2007; Wan et al., 2016; Yamaguchi et al., 2008), whereas air transport is found to be the dominant mode, with market share varying between 50% and 80%, for travel distances over 1,000 km (Givoni, 2006; Janic, 2003). However, Rothengatter (2011) pointed out that the distance range that saw fierce competition between civil aviation and HSR is from 400 to 800 km. Zhang and Zhang (2016) used gravity models to examine the determinants of air passenger flows in China with the HSR presence as one of the explanatory variables and found that the length of air routes that are subject to HSR competition could extend to as long as 1,300 km. These seemingly contradictory findings about the dominant distance range of air transport over HSR is not that surprising, because what matters more is the actual travel time – the HSR train speed can vary significantly in different markets and during different time periods.

Existing studies almost exclusively focus on the travel-time effect of HSR speed on airlines. For example, theoretical papers by Yang and Zhang (2012) and Xia and Zhang (2016) investigated how travel times of HSR and airlines can affect passengers' choice of travel modes. In an empirical study, Dobruszkes (2011) recognized HSR travel time as the key competitive factor in air-HSR

[7] For example, almost 1.2 billion Chinese passengers took HSR service in 2015, and one-way frequency between Shanghai and Nanjing – the busiest HSR route – was 204 (including both OD and passing lines) per day in October 2016 (Wang et al., 2017). A main channel through which frequency influences service quality is the schedule delay cost, which refers to the difference between a passenger's preferred and actual travel time. More frequent service reduces expected schedule delays and hence is a more convenient service, which in turn increases demand.

[8] In addition to speed, factors such as comfort, convenience, safety and punctuality may affect passengers' modal choice (e.g., Olivier et al., 2014)

competition in the Western European market. Dobruszkes et al. (2014) reported, based on analyses of 161 routes EU-wide using transnational data, that the commissioning of new HSR services caused airlines to adjust their strategies: in particular, air services are affected by HSR travel time, i.e., the longer the HSR travel time, the more air services.[9] Capozza (2016) tested HSR travel time on airfare using the market data of Italy and found that airlines set, on average, higher fares as rail travel time increases. Zhang et al. (2017a) also found that airline demand decreases with shorter HSR travel time in the Chinese market. Li and Loo (2017) found that airline demand in China decreases with the increase of railway speed (i.e., shorter rail travel time), but this effect only manifests on short-haul routes (less than 1,100 km as defined in the paper). Jorritsma (2009) concluded that the HSR occupancy rate could reach 50%-90% if travel time of HSR is within 2 to 3 hours. Clewlow et al. (2014) found that the improvement of rail travel time has a significant impact in reducing short-haul air traffic.

There are two empirical studies that examined explicitly the effects of HSR travel speed on Chinese airlines. Wei et al. (2017) investigated the HSR substitution for air travel through the demand shocks triggered by two railway events: the launch of Beijing-Shanghai HSR service and the Wenzhou train accident. The two events are exogenous to the airline industry, alleviating the common endogeneity concern. Using airline ticket prices published on a booking agency website and a difference-in-differences (DID) approach, the authors found some evidence of substitution based on the pattern of airfare adjustments during the sample period.[10] Specifically, compared to those in the control group, average airfares for routes along the Beijing-Shanghai HSR route declined by 30.4% upon the launch, but rebounded by 27.4% following the accident. Furthermore, the two events have a larger impact on LCCs and regional airlines, on tourism routes, and on flights that departed during evening hours than their respective counterparts. They concluded that the HSRs mainly served as a low-end substitution for air travel in China.

Wang et al. (2018) studied the effects of HSR travel speed on (equilibrium) airline traffic and fare both theoretically and empirically. Their empirical study applied the DID method to the Wenzhou train accident, which is a rare natural experiment of HSR speed reduction in China. The authors found: First, the “travel time” effect due to HSR speed change dominated the “safety”

[9] On the other hand, the impact of HSR frequencies was found to be much more limited.
[10] The authors manually collected the announced airline ticket prices from the largest travel agency www.ctrip.com in China.

effect: While increasing HSR speed reduces HSR travel time and thus lowers airline demand (the travel-time effect), it may bring about a safety concern especially in emerging HSR markets such as China (the safety effect) – leading to a negative HSR speed effect on airlines. Second, the entry of HSR on short-haul (e.g., less than 850 km) routes had larger negative impacts on airline (equilibrium) traffic and price than on long-haul routes. Third, the elasticities of airline traffic and price with respect to HSR speed were larger in magnitude on short-haul routes and at higher HSR speeds. This (and the second result) is consistent with the finding of Dobruszkes et al. (2014), but is in the first time quantified in terms of the elasticities of airline equilibrium traffic and price. Finally, there was a positive and statistically significant accident effect with daily data, but this accident effect was small in magnitude and vanished with quarterly data.

### 2.3 Effects of HSR on airfare and airline market power

HSR entry may effectively reduce airlines' market power and hence fare via air-HSR competition. Ma et al. (2019) examined such effects using the busiest and most profitable HSR line in China (the Beijing–Shanghai line) that parallels airline service. The authors found that both airfare and air demand fell significantly after the entry of Beijing-Shanghai HSR. In particular, economy-class airfares dropped more than business-class airfares but, somewhat surprisingly, the decline in the business-class demand was larger than that in the economy-class demand. Although HSR frequency and the number of HSR seats appeared to have no significant impact on airfares, they were significantly and negatively associated with air demands, especially the demand for business passengers. Zhang et al. (2017a) found a negative relationship between airfare and HSR frequency in China. However, the authors argued that the impact of HSR frequency on airfare is much weaker than the impact of HSR travel time. HSR services are more punctual than airline services and are less likely to be affected by bad weather conditions (see also Chen and Wang, 2018).

Zhang et al. (2014) used the Lerner index to measure the market power of Chinese airlines and found that HSR is one of the most important determinants of airline market power. Zhang et al. (2018b) examined the impact of HSR on market concentration, measured by the Herfindahl–Hirschman index (HHI) and the Lerner index, in China's airline market. They found that in general, the entry of HSR had the effect of reducing market power measured by both the unweighted and weighted Lerner indexes. On the other hand, the Lerner index and HHI of the routes with parallel HSR services remained consistently higher than those of the routes without parallel HSR services, suggesting that HSR also has an effect on airline market structure. Qin (2018) found that the introduction of HSR increases airline concentration (HHI) measured by the number of routes operated by individual airlines in a Chinese city. Due to low air-to-air connectivity, airlines with weaker presence in the city are more likely to exit rather than compete with HSR and as a result, the share of the city's dominant carriers increases.

### 2.4 Effects of air-HSR cooperation

In addition to air-HSR competition, an emerging body of theoretical literature focuses on air-HSR cooperation in that the two modes make joint decisions, or offer intermodal service. Essentially, there exists complementarity between the two services. For example, Jiang and Zhang (2014) considered a joint-decision making scenario under hub airport capacity constraint and compared it with the independent-decision making (competition) benchmark with respect to profit, consumer surplus and social welfare. Xia and Zhang (2016) investigated the competition and cooperation between HSR and air by adopting a vertical differentiation approach and found, among others, that in the HSR-inaccessible market, HSR-air competition may lead to higher airfare in the connecting market. This stream of literature remains largely theoretical. Section 3.1 below will discuss papers that explicitly analyze the impact of air-HSR cooperation on airport traffic, whereas the impact on regional economies will be discussed in later sections.[11] There, a basic premise for HSR-air intermodality is modal complementarity: HSR (air, respectively) may serve as a feeder for air (HSR, respectively) routes. By developing a model, Kroes and Savelberg (2019) estimate the potential for HSR travel as a substitute for short-distance air travel at Amsterdam Airport. The model predicts a reduction of 2.5% to 5% of all flights to/from Amsterdam Airport in 2030 (as a result of HSR substitution).

We are not aware of any empirical paper that explicitly measures the impact of air-HSR cooperation, probably because cooperation itself is difficult to observe or quantify. However, as the intermodal alternative has been practiced with or without cooperation between air and HSR,[12] we do find some empirical studies that identify the influencing factors for passengers' choice of air-HSR intermodal service. In the Chinese market, Li and Sheng (2016) studied the mode choice

[11] Note that Xia et al. (2018) contained a literature review on HSR-air modal integration.

[12] Examples include the cooperative arrangements between Deutsche Bahn trains and Lufthansa Airlines (especially on some short-distance routes emanating from Frankfurt), between Thalys trains and Paris Charles-de-Gaulle Airport, and between China Eastern Airlines and the Shanghai Railway Bureau (Jiang and Zhang, 2014; Xia and Zhang, 2016; Song et al., 2018).

behavior of inter-city passengers among airline, HSR, and air-HSR integrated services using a stated preference survey on the Beijing-Guangzhou corridor. Modal split models were proposed and calibrated based on the collected survey data. The proposed models were then used to identify the key factors affecting passengers' mode choices, and to estimate the modal split of passenger travel demand for some inter-city transportation markets of China. Sensitivity analyses were also performed to predict the market potential of the air-HSR integration service. The authors found, among others, that the transfer time is essential for Chinese passengers to select the air-HSR intermodal service. Brida et al. (2017) analyzed passengers' preference by a stated choice experiment at Madrid-Barajas Airport and identified a segment of passengers who prefer air-HSR intermodal service. These passengers tend to travel to the central business district, work or have a meeting during the trip, or use mobile phones and Wi-Fi during the trip, and they tend to be younger in age. Based on stated-preference data collected in Shanghai, Song et al. (2018) found that variety seekers would be more likely to choose the newly-introduced integrated HSR-air option and that long layovers would heavily impair the attractiveness of integrated HSR-air service whilst integrated luggage handling services would attract intermodal passengers.

## 3. Impact on Airport Traffic

Since HSR serves as an effective substitute to short/medium-haul air flights (as discussed in Section 2), one may predict that air traffic will fall after the introduction of HSR services. This prediction appears to play a key role in many policy makers' arguments for using HSR, or air-HSR intermodal transport, as a solution to airport congestion and to excessive emissions from air flights (CEC, 2001; European Commission, 2010; 2011). As we discuss below, this conclusion might be reached too fast.

In fact, that air traffic *rises* on routes with overlapping HSR services has been observed in several recent studies. Albalate et al. (2015) compare three types of air routes with parallel HSR services: (i) routes with a hub airport as an endpoint and an on-site HSR station at the hub airport; (ii) routes with a hub airport as an endpoint but no on-site HSR station; and (iii) routes without a hub airport as an endpoint. They found negative (in general) but statistically insignificant impacts on the routes with hubs and on-site HSR stations (e.g., Paris-CDG and Frankfurt) and strong, negative impacts on the routes with hubs but no on-site HSR stations (e.g., Paris-Orly, Madrid, Rome, and Milan). However, on the routes linking two spoke airports, they found a much milder or even positive impact in France, Spain and Italy, but a strong, negative impact in Germany. In long-haul markets, although most studies found little impact on air traffic after the parallel entry of HSR, significant air traffic increases were observed in China on routes over 800-1,000 km (e.g., Wan et al., 2016; Zhang et al., 2018a). Qin (2018) also observed an increase in the number airlines on certain overlapping long-haul routes. More surprisingly, according to Qin (2018)'s simulation study, airlines may also drop routes without parallel HSR service (i.e., not directly competing with HSR). In other words, to understand the impact on airports, one must take into account the network nature of airline business as well as both the substitution and complementary impacts of HSR.

The provision of air-HSR intermodal service would substantially complicate the picture, because air traffic might be affected not only in the overlapping markets, but also in the segments that HSR is unable to access (for example, inter-continental air travel). Intuitively, HSR may increase air traffic on the HSR inaccessible route segments if HSR can effectively extend the airport's catchment to areas which used to be underserved by air transport due to high ground access cost.[13] However, if HSR connects two airport cities, it may intensify the competition between those airports and one may question if the smaller airport will be disadvantaged, as the larger airport may have better international connection and hence can attract more passengers flying to international destinations from the smaller airport.

### 3.1 Impact of air-HSR cooperation (theoretical studies)

Several theoretical studies have discussed, either directly or indirectly, the impact of HSR on *airport traffic* by taking into account air-HSR intermodal services, but none have compared the (equilibrium) outcomes before and after the HSR entry. These studies have instead evaluated how air-HSR cooperation (or integration) would play a role. The net effect of air-HSR intermodal cooperation on an individual airport could depend much on the airport's accessibility to HSR inaccessible markets, its attractiveness to passengers from the competing airports, as well as changes in market structure of the city-pair markets. The basic modeling framework can be traced back to Socorro and Viecens (2013) and has been modified in various follow-up studies.

#### *1) Unequal access to HSR inaccessible markets*

[13] In addition to the catchment area expansion, airlines may intentionally add more routes (or destinations) that are not accessible by HSR, such as certain international flights and long-haul flights (Jiang and Zhang, 2016).

Figure 1 illustrates the basic network structure used in this stream of literature. There are three cities (denoted as A, B and H) and three city-pair markets (AH, HB and AB) in the network. In the baseline setting, HSR connects two cities, one with a hub airport (H) and the other with a spoke airport (A). Airlines offer non-stop service in the AH and HB markets while the AB market is served by connecting flights in AH and HB segments via H.[14] That is, city B (the third region that is not feasible for HSR service) is only accessible by airport H but not by airport A. HSR service, on the other hand, is only available in the HB market, but it is possible to combine HSR service in the AH segment and air service in the HB segment to serve the AB market. A real-life example would be a network of Valencia, Spain (for A), Madrid, Spain (H), and Hong Kong (B).

[Insert Figure 1 here.]

Table 1 lists the various settings applied by representative papers that assume HSR connects a hub airport and a spoke airport (as depicted in Figure 1). Air-HSR cooperation is mainly modeled by having the airline and HSR jointly maximize profit and set quantity (or price) for the air-HSR intermodal product in the AB market. Note that the last row is the case in which an airline and HSR make decisions separately, but the quality of the air-HSR option is improved by a shortened transfer time between the airport and HSR station. The traffic impact in individual city-pair (OD) markets depends much on model settings, including the number of airlines in the HB market,[15] the accessibility of the cooperating airline to the AH market, the availability of air-HSR option in the AB market prior to the cooperation, the availability of air-air option in the AB market after the cooperation, and other differences in detailed model assumption. All the papers listed in Table 1 assume a hard constraint on the total traffic that can be handled by the hub airport H. The traffic impacts summarized in Table 1 are based on the case where the hub airport capacity constraint is not binding.

[Insert Table 1 here.]

All the papers in Table 1 study a case where the hub airport H becomes more accessible to the AB market after air-HSR cooperation or quality improvement, while airport A remains inaccessible to the AB market (i.e., no direct flights between A and B). In most of the cases air

[14] This hub-and-spoke network was initially analyzed in the context of rivalry between airlines in Oum et al. (1995).
[15] All the surveyed papers assume a single airline in the AH segment, although some of them do allow more than one airline in the BH segment.

traffic in the AB market tends to rise, due to the improved access with HSR's traffic feeding, and this drives up air traffic on the HB segment with one exception based on Xia and Zhang's (2016) finding. Air traffic in the AH market is likely to fall, but when the air-HSR connection at the hub is improved, a reduction will not necessarily occur (e.g., Xia and Zhang, 2016). This latter theoretical prediction about AH market appears consistent with the empirical finding of insignificant traffic reduction on the routes linked to hub airports with on-site HSR station in Europe (Albalate et al., 2015). Air traffic in the seemingly irrelevant HB market may increase or decrease (e.g., Xia and Zhang, 2016). Most of the papers do not provide explicit assessment on total traffic on each route segment (leg) or the net impact on total airport traffic. However, the mixed results on city-pair markets suggest a high chance of having mixed results on route segments and airport traffic. In general, traffic at spoke airport A is very likely to fall while a net traffic increase at airport H is promising. Both airport A's lack of connection to HSR inaccessible region (B) and the unilateral accessibility improvement at airport H contribute to airport A's failure to counteract the substitution effect of HSR. In fact, based on a model similar to Jiang and Zhang (2014), Avenali et al. (2018) show that an increase in the airport H's total traffic will occur under certain conditions.

When the hub airport's capacity constraint is binding, total airport traffic will never increase under the air-HSR cooperation while total traffic reduction is possible under some conditions. However, the traffic distribution among different air routes will change after the cooperation. In most of the cases, the airline may reduce traffic or even abandon its operation on the AH leg (Socorro and Viecens, 2013; Xia and Zhang, 2016) while adding traffic to the HB leg (Socorro and Viecens, 2013). However, the origin-destination (OD) traffic of the HB market may not necessarily rise (Jiang and Zhang, 2014; Sato and Chen, 2018). This suggests that at capacity constrained airports, HSR will not only replace some air flights in the AH market to provide feeding to HB market but also induce new demand for air-HSR intermodal itinerary in the AB market.

***2) Dual access to HSR inaccessible markets***

Another stream of papers extends the above model to study the interaction between two hub airports, both accessible to the third region (B). Takebayashi (2015) models a system of two airports of interest (A and H) by adding an air link on the AB segment in Figure 1. Airports H and

A compete for international passengers destined to city B (the third region not accessible by HSR); as such, H and A may be referred to as “gateway airports”. As city centers of these two airports are linked by HSR, travelers in city A (city H, respectively) can take a flight from airport H (airport A, respectively) with an HSR ride. Everything else being equal, airport A has weaker access to the HSR station (e.g., higher airport-HSR station connection cost). He finds that compared with airport H, airport A will serve more air-air connecting passengers but fewer air-HSR connecting passengers, fewer passengers taking direct flights in the AB market, and consequently fewer total passengers. If airport H is a larger gateway hub with higher demand for international flights (HB) and airport A is a smaller gateway with lower demand for international flights (AB), airport H tends to be more attractive to passengers who want to fly to city B, since larger demand can be translated into higher flight frequency on the HB segment. However, lowering the connection cost between the smaller airport (A) and the HSR station in its city center may substantially improve the small airport’s gateway position in terms of attracting international passengers from the larger airport by air-HSR connecting service. Moreover, this type of improvement is more effective when the demand difference between the airports is larger.

Takebayashi (2016) extends the model by investigating the role of airport-HSR cooperation in diverting traffic to the smaller airport (A) and thus mitigating congestion at the larger gateway airport (H). The airport-HSR cooperation is in the form of maximizing airport-HSR joint profit and subsidizing international passengers who choose an air-HSR intermodal service. He concludes that cooperation between HSR and the larger gateway airport is not desirable, but cooperation between HSR and the smaller airport is desirable. Basically, in this multi-airport system cooperation with the larger airport simply increases connecting passengers, especially air-HSR passengers; these connecting passengers will displace non-stop passengers and reduce system-wide total traffic (A+H). Furthermore, the larger cooperating airport might attract too many air-HSR connecting passengers, thereby worsening its congestion. On the other hand, cooperation with the smaller airport not only increases the system-wide connecting passengers but also total air traffic in the multi-airport system.

Xia et al. (2019) apply a similar network setting, but with substantial simplifications, to focus on the incentives to form partnership by the HSR and airports. They assume: (i) HB is the only OD market in concern; (ii) cities A and H are linked only by HSR (due primarily to the distance being too short to fly); (iii) each airport forms a single entity with all the airlines operating at the airport, i.e. air sector H and air sector A; and (iv) air-HSR cooperation is only feasible between HSR and air sector A. A new feature is that their cooperation scheme includes air sector A's reimbursing HSR tickets to air-HSR passengers, and HSR's sharing ticket revenues with air sector A. This cooperation scheme is shown to achieve a better traffic distribution by diverting some traffic from the busier airport to the smaller airport, and to improve consumer surplus as more passengers will travel in market HB. They also find that social welfare tends to rise especially when congestion at the larger airport is severe, but that profits of air sectors and HSR may increase or decrease. Therefore, despite the positive impacts on airport traffic, consumer surplus and social welfare, this type of air-HSR cooperation may not arise automatically. They further show that cooperation tends to be achieved when the HSR operator is welfare-oriented or when air sectors A and H are monopolized. As the Chinese case fits these conditions to some extent, they predict this type of air-HSR cooperation to appear in China. In the context of private HSR operators and highly competitive airports, such as the case of Europe, this type of cooperation is less likely to occur and may require policy interventions.

### 3.2 Airport traffic redistribution effect of HSR

The above literature review suggests that HSR can have a "traffic redistribution" effect on airports. Traffic might be more evenly distributed among airports in certain cases whilst, in other cases, becoming more concentrated at a few major airports. Roughly, there are three mechanisms through which the distributional inequality is increased (or reduced):

(i) When the feeding role of HSR is negligible, all airports may suffer traffic loss, while those airports with better flight connections (e.g., hubs) may suffer less than the others.

(ii) When the HSR's feeding role is present, airport traffic distribution can be affected by unequal improvements in accessibility to non-local markets, especially those inaccessible by HSR. All the papers reviewed in Section 2 fall into this category, where market HB is the non-local market for airport A and market AB for airport H. Regardless of model settings, they all consider a case that one airport enjoys a better accessibility improvement than the other. Unsurprisingly, if larger and well-connected airports receive more accessibility improvement than the others, these larger airports will experience more favorable traffic change than the smaller ones. Note that this "favorable traffic change" is relative to other airports. It may not indicate a net traffic increase at the airport since the substitution effect of HSR can be too strong to overcome, but the distributional inequality is likely to be enhanced. Of course, airport traffic might be more evenly distributed if only small airports' accessibility improves. Xia et al. (2019)'s model provides one example of improving small airports' access to a market originally served only by the large airport. Their analysis shows that this type of airport-HSR cooperation is difficult to achieve as it may not be profitable for airports and HSR, though a better traffic distribution can be achieved together with an enhanced social welfare.

(iii) The last possible mechanism plays a role when HSR does not cause differentiated improvement in accessibility but helps potentially rival airports to access each other's catchment and increase competition. Then, intuitively airports with larger size (and better flight connectivity and higher frequency) are likely to win traffic from the weaker ones, due to the economies of scale and network size. Nevertheless, if the larger airports are highly congested, unsatisfied travel demand may spillover to the smaller airports which can be easily accessed by HSR, as the diseconomies of scale arises. To our knowledge, this impact of HSR has yet been explicitly explored, analytically or empirically, in the air transportation literature. Takebayashi (2015, 2016) models two competing hub airports, but the analysis is limited to asymmetric accessibility change as mentioned in the second point and hence provides little insights on the third mechanism.

In practice, more than one mechanism may be simultaneously at work, and it is therefore important to measure the HSR's impact on airport traffic empirically. Here the literature is much smaller than the literature on route-level impacts (airport pairs or city pairs). Table 2 presents the airport-level empirical studies and their methodological details. These studies are to be discussed below.

[Insert Table 2 here.]

Based on interviews and case studies, Clewlow et al. (2012) find that at the Paris-CDG and Frankfurt airports, domestic traffic declined while international traffic increased due to the integrated air-HSR services. To our knowledge, Clewlow et al. (2014) provide the first airport-level regression analysis with data from Europe. They find a strong negative impact on domestic air traffic, but a much milder or even insignificant negative impact on intra-EU traffic and total traffic. Similarly, Zhang et al. (2017b) calculate the flight connectivity[16] of 69 Chinese airports and identified the underlying drivers of the variation in airport connectivity over a period 2005–2016. The authors find that HSR has the effect of decreasing the overall and domestic airport connectivity due to its high substitutability for air transport but its impact on international connectivity is statistically insignificant. By including all Chinese airports in their study, Li et al. (2019b) find that on average HSR reduced air passenger growth rate by 8.5% in 2015 but rapid economic growth can make air traffic continue growing. Castillo-Manzano et al. (2015) propose a dynamic linear regression approach and estimate how the expansion of the Spanish HSR system (measured by the number of HSR passengers in the entire HSR system) over time has affected the domestic air passenger traffic at the Madrid-Barajas airport. The study reveals a negative effect of the HSR passenger number on domestic airport traffic. Moreover, from January 1999 to the end of 2007, as new HSR lines linking less populated cities were added into the system, the degree of such airport-traffic reduction diminished. As a result, in the 1999-2012 period, only 13.9% of HSR passengers were diverted from air transport. Based on this finding, the authors question the existence of HSR network effect in terms of attracting passengers away from air transport.

The above studies focus on the net impact on a specific airport or the average impact on a sample of airports, after balancing the substitution and complementary effects, but they provide little insight on spatial inequality of airport traffic. Some recent empirical studies tried to better quantify the impacts by distinguishing substitution and complementarity between air transport and HSR (e.g., Qin et al., 2018; Zhang et al., 2018a; Liu et al., 2019). Instead of studying the impacts on air traffic, Qin (2018) focuses on airlines' domestic route entry behaviors in China. The substitution effect is found to dominate the complementary effect, leading to an overall reduction in the number of routes operated by airlines. Cities (airports) located in Central and Eastern areas of China are mostly affected due to a high percentage of air routes encountering parallel HSR services. Improving the positive spillover from HSR can effectively increase airlines' route presence if the city has a moderate level of HSR connections.

[16] Flight connectivity constructed by Zhang et al. (2017b) is a weighted sum of scheduled flight movements at the airport. The weight is determined by the relative seat capacity and the relative velocity of each flight. The velocity takes into account time spent at the departure, arrival and intermediate airports.

Zhang et al. (2018a) add to this stream of literature by estimating the impact of on-site HSR stations on the airport-level traffic using airport data from both East Asia and Central Europe. By focusing on the feeding (complementary) effect of HSR on airport traffic, the authors are able to capture the differential impacts of HSR on airports. They find that on-site HSR stations increased air traffic at primary hub airports while the impact on secondary hubs and regional airports was insignificant. Furthermore, the impact at hub airports is stronger in Central Europe than in East Asia. This finding suggests that a possible inequality in the HSR's accessibility improvement effect may exist between the primary and secondary hubs at a world-wide scope. However, Zhang et al. (2018a) do not compare the net traffic impacts between the hub and non-hub airports by also taking the substitution effect into account.

Liu et al. (2019) do compare the net traffic impact; moreover, they consider the spatial difference of airports' location in the HSR network. Using the detailed HSR timetable data in China and Japan, they calculate both the "degree centrality" and "harmonic centrality" of an airport's city within the national HSR network to reflect, respectively, the connectivity and accessibility of the city to other cities with HSR. They also identify the potential complementary effect of HSR by including an interaction term between the centrality measure and the presence of a convenient airport-HSR station transfer linkage. In general, in the case of China, as the connectivity or accessibility grows, hub airports experienced a net traffic growth, while non-hub airports experienced a strong traffic reduction. Such traffic growth at a hub airport is even more substantial with a good airport-HSR station linkage. The main source of traffic increase comes from HSR's feeding to international flights and little change in domestic traffic. The traffic-reduction effect at non-hub airports mainly comes from the domestic traffic reduction and a limited change in international traffic. Adding an airport-HSR station linkage did not help a non-hub airport to grow traffic a lot (both domestic and international), but it might be helpful to balance the substitution and feeding effects since the net effect of improved HSR connectivity tends to be statistically insignificant at non-hub airports with airport-HSR station linkage. In Japan, however, both centrality measures were found to have little impact on domestic traffic (except for some negative impact on hub airports without airport-HSR station linkage) but they had some positive effect on international traffic. Furthermore, regardless the hub status, having airport-HSR station linkage helped to boost international (and total) traffic in Japan, although the effect on non-hub airport was smaller.

Liu et al. (2019)'s finding suggests an increased inequality of traffic distribution between the hub and non-hub airports in both China and Japan, since hub airports seem to be more favored by HSR entries than non-hub airports (Sun et al., 2018). This finding is consistent with that of Zhang et al. (2018a). Furthermore, Liu et al. (2019) discover a net traffic loss at non-hub airports and a net traffic increase at hub airports, thus suggesting a possible traffic diversion from the non-hub to hub airports in China. Although this finding sheds some light on the third mechanism discussed above, it provides no direct evidence on the presence of this mechanism. One may come up with another explanation. For example, the traffic loss at non-hub airports can be simply caused by the HSR substitution effect while the traffic gain at hub airports may be contributed mainly by an induced (instead of diverted) demand for international or long-haul flights which would not exist without HSR.

## 4. Policy Relevance of Airport-Traffic Effects

### 4.1 Airport congestion and traffic redistribution

Empirical findings discussed above question, at least indirectly, the effectiveness of using HSR to mitigate airport congestion. The possible traffic redistribution (or probably diversion) from non-hub to hub airports (Liu et al., 2019) and more concentrated traffic at hub airports (Zhang et al., 2018a) may worsen the already low "cost recovery" ability of small, regional airports in a hub-and-spoke airport network (Kidokoro and Zhang, 2018) while at the same time exacerbate congestion at large hubs. The possibility of increasing distributional inequality appears much lower in the developed regions, such as Europe and Japan, than in China.

Furthermore, the high level of regional inequality in economic development that has prevailed in emerging economies, such as China, may contribute to the increased inequality in airport traffic. This is because HSR may facilitate the exploitation of agglomeration economies and, consequently, attract more business activities at a few major cities. As primary hub airports usually locate in these well-developed cities, the increased economic activities further stimulate air travel demand at primary airports. (The impact of HSR on the redistribution of economic activities will be discussed in the next section.) This negative traffic-redistribution effect of HSR development warrants more attention in policy debate concerning HSR. Relatedly, policies that favor the regional airports that are negatively affected by HSR may be useful to achieve a better traffic distribution among airports, instead of further expanding a few large hub airports.

Moreover, given that a good air-HSR intermodal linkage (e.g., airport on-site HSR station, airline-HSR cooperation, etc.) tends to make airports suffer a less traffic drop or enjoy a more traffic gain, policy makers may consider this as a tool to achieve a better airport traffic distribution. For example, air-HSR intermodal service can be encouraged at small airports while discouraged at large airports. Of course, promoting the air-HSR intermodal service alone may not be enough; the "small airport" in concern must add sufficient connections to international destinations so as to attract passengers away from the primary airport. This requires a strong local travel demand, which in turn would require the city of the "small airport" to have sufficient economic activities and income levels. Some local governments may try to stimulate international traffic by subsidizing these flights, but it is not sustainable unless the local demand can surge within a short period of time. China has been heavily subsidizing direct intercontinental flights out of second-tier cities (such as Chengdu, Shenyang, Xi'an, and Hangzhou) over the past several years. The total subsidy (eligible for both domestic and foreign operators) was USD1.3 billion in 2016 (Bloomberg News, 2017). However, several foreign airlines have dropped these services since 2016, possibly because demand failed to grow to a satisfactory level by the end of the subsidizing period. The key point is: On-site HSR and other policies that promote air-HSR intermodal service only provide a potential for connection and traffic movement. However, such a potential won't be realized if the local economy is too poor to be worthwhile for a connection (Campante and Yanagizawa-Drott, 2018). Therefore, to divert excessive traffic out of congested primary hubs, secondary airports located in cities with very low income and low growth potential should not be targeted. Meanwhile, appropriate plans to either attract international business activities or convert the airport into an airline's hub should be provided, together with air-HSR promotions.

To improve the connection between the airport and HSR station whenever desired, sufficient incentives should be provided to railways and the air sector, because extra investment is needed to link the airport to the HSR network (Givoni and Banister, 2006). Theoretically, when the airport's runway capacity is severely constrained, both the air and rail operators may benefit from improving air-HSR connection, together with an increase in consumer surplus and social welfare (Xia and Zhang, 2017). Therefore, airlines and railways have strong incentives to invest in the air-HSR intermodal infrastructure by themselves. However, when the runway is not seriously congested, the issue is more complicated. Air and rail operators have low incentives to invest in the intermodal connection despite the gain in consumer surplus and social welfare, because these two modes compete in certain markets (Xia and Zhang, 2017). Of course, if they cooperate, sufficient joint profit can be achieved and shared between the two to induce their investment, but the reduced competition could harm consumers. In this case either a public entity should invest in the intermodal infrastructure, or the regulators should assess the trade-offs before approving the cooperation on investing air-HSR connection and if approved, then monitor the investment ex-post.

### 4.2 HSR as a tool to protect environment

The environmental impact of CO2 emissions has attracted increasing attention in recent years, which in turn has important implications for the modal choice between air and rail transport. HSR, and rail in general, are widely regarded as a more environmentally friendly substitute to air transport, as the mode involves less marginal (per-passenger) environmental damage than air transport (e.g., Givoni and Dobruszkes, 2013; Zhang et al., 2004). While a full analysis of the issue is beyond the scope of the present paper, we note an environmental implication of the possible air traffic growth at certain airports discussed above. Such growth possibilities might raise concerns about the effective emission reduction via the modal substitution (Socorro and Viecens, 2013). Further, both theoretical and empirical studies seem to suggest that air-HSR integration might impose a threat to the environment, as HSR tends to feed international flights that emit more relative to short-haul domestic flights due to longer flying distance. Therefore, a nation-wide flight emission study taking into account both the substitution and complementary effects of HSR is essential to better understand the overall air-related emission change contributed by HSR. However, such studies are, to our best knowledge, yet available in the literature.

The existing studies of HSR's environmental impact focus mainly on route-level competition with other modes, e.g. air. Even though we ignore the traffic-feeding impact of HSR, it is still not clear whether HSR can reduce emissions. D'Alfonso et al. (2015) model a single non-stop OD market that is originally served by an airline. The entry of an HSR operator into the market then creates competition with the airline for passenger traffic. They find that although the entry of HSR reduces the airline's traffic, the newly generated HSR traffic offsets the air traffic reduction and leads to an increase in the total number of trips in the market. Thus, if HSR fails to emit sufficiently less than does the airline, the total amount emission will increase rather than decrease. In other words, the marginal travelers who are induced to travel by HSR may fail to generate a sufficient amount of surplus to compensate the environmental cost of their trips. When this is the case, the more attractive is HSR service relative to air transport, the more environmental damage would be caused by the entry of HSR. Applying this model, D'Alfonso et al. (2016) conduct a simulation study based on the London-Paris market and find that the entry of HSR into this market causes more local air pollution but reduces greenhouse gas emission. However, based on a panel of 104 city-pair air routes over 20 years in China, Li and Loo (2017) first estimate the railway speed elasticity of air patronage for city pairs within 1,100 km by regression analysis and then estimated that if rail speed increased from 120 km/h to 300 km/h in these markets, air patronage would drop by 25.5%. Based on this estimation, they predict that if all the air traffic reduction were replaced by HSR, the total CO2 emission (air plus rail) would reduce by 6.9% based on the 2010 scenario. Wang et al. (2019) estimated that during the 2012-2015 period, although the substitution effect of HSR cut 8 million tons of CO2 emission from domestic flight operations in China, the net saving of CO2 emission was only 1.76-2.76 million tons after taking into account the emission from generating electricity for HSR operation, accounting for only 3.2-5.1% of domestic aviation emission in 2015.

It is not sufficient, of course, to only consider the environmental impact during operation, since HSR indirectly emits greenhouse gas. Construction and maintenance of HSR infrastructure require consumption of various materials (e.g. steels and concrete) while the production of these materials is energy intensive. Ha et al. (2011) empirically investigate the environmental burden of rail and air transport modes by taking into account the CO2 emissions from both transport service provision and infrastructure construction. Using a panel data set from 1999 to 2007 for three Japanese railway companies and the Japanese air transport industry, which are treated as decision-making units (DMUs), the paper estimates the social efficiency of these DMUs via a nonparametric productivity measurement method that incorporates economic bads as undesirable outputs. The aviation industry is shown to be efficient, whereas results for the railway industry are mixed, depending on individual companies. Westin and Kågeson (2012) conduct Monte Carlo simulation to estimate the required amount of traffic diversion from other modes, including short-haul flights, long-distance buses, cars, and conventional rails, to offset the "embedded" emission from constructing a 500 km HSR line. They find that to achieve a net emission reduction, HSR needs to attract at least 10 million annual one-way trips (about 10% annual passenger traffic at Atlantic airport) from other modes of transport, and the majority of this diverted traffic has to come from air transport. Empirically, Clewlow et al. (2014) and Castillo-Manzano et al. (2015) observe an overall negative impact on airport traffic, but the magnitudes are not large, suggesting a weak ability to offset the environmental costs of HSR construction.

Although the present paper focuses primarily on the impacts of HSR on air transport, one must take a broader picture to include not only substitution effect among various modes of transport but also the amount of induced travel demand when assessing the environmental impact. First, among all transportation modes, air travel demand tends to reduce the most facing the entry of HSR, but the largest source of HSR passengers is the conventional rails. As the conventional rails consume less energy than HSR on the per seat-km basis (Kageson, 2009), this group of passengers in fact emit more due to HSR. Although road users may be attracted to HSR, but an indirect increase in car trips is possible. For example, a research conducted by European Commission found a 23% increase in car passengers on the Madrid-Seville route after the launch of HSR (Givoni and Dobruszkes, 2013). If the introduction of HSR causes a reduction in conventional rail investment and services, some conventional rail users may shift to road, because cars are more flexible than HSR and HSR fares can be quite expensive. Second, in a specific city-pair market, the introduction of HSR may induce new trips that would not have taken place without HSR. After reviewing many studies, Givoni and Dobruszkes (2013) conclude that about 20% of the demand for HSR services is induced within a few years after its entry. In fact, similar to the case of airport traffic mentioned above, even with strong modal substitution towards HSR, other transportation modes may not see a sizable traffic reduction as freed capacity can be filled up by induced demand quickly. Therefore, without a thorough understanding on the behaviors of passengers and operators and a comprehensive assessment involving all relevant transportation modes, it may be premature to conclude HSR's positive impact on environment.

## 5. Redistribution of Economic Activities and the Siphon Effect

In the context of urban development, the presence of agglomeration economies may lead to a so-called "siphon effect." That is, resources, such as talents and investment, tend to flow from small cities to large cities, as the latter possesses better infrastructure, greater variety of products and services, a larger market, and many other factors that improve efficiency of doing business. HSR entry changes the accessibility of individual cities to non-local markets, resources and investors, and so this may affect the distribution of economic activities and play a role in the siphon effect.

For instance, Zhu et al. (2018) considered both quality and quantity of the inter-city passenger connections of 23 major cities in China. Their study includes two transport modes: airline and railway, where HSR is a main railway mode for passenger services. Shanghai is revealed to have the highest connectivity level, leading in both air and rail connectivity. Shanghai-Nanjing has been found to be the best-connected city pair, primarily due to the significant contribution from HSR service. The authors showed that HSR has become a preferred and dominant option over air on a number of long-distance routes up to 1,300 km. This finding suggests that HSR can substantially change a city's accessibility to other cities.

There are two seemly contradictory predictions. One suggests that smaller cities can benefit from HSR by improving these cities' access to non-local markets and major cities. Better accessibility can attract investment and various economic activities, which help the smaller cities to grow and reduce spatial inequality between the rich and poor regions, i.e., to mitigate the siphon effect. Many policy makers consider this mitigation role as one of the major reasons for developing HSR. For example, in China, the extensive HSR network is supposed to facilitate the development of second-tier and third-tier cities by connecting them to megacities (such as Shanghai, Beijing, Guangzhou, and Shenzhen).

The other prediction suggests that HSR linkage may reinforce the siphon effect and thereby increase spatial disparity. The argument is similar to the core-periphery theory introduced by Krugman (1991) in the field of New Economy Geography. According to the theory, two economic forces play a role in the movement of economic activities: The agglomeration force tends to make economic activities more concentrated around a few large cities, leading to increased spatial disparity. Meanwhile, the dispersion force attracts economic activities to a large variety of locations and hence results in spatial convergence, i.e., more balanced amount of economic activities between large and small cities. Cost reduction in inter-city transportation may contribute to spatial competition between the large and small cities and make the agglomeration force overcome the dispersion force, resulting in increased regional inequality in economic development. On the other hand, Krugman (1991)'s model has been extended to explain cases where substantial reduction in transportation cost may contribute to less concentration and achieve spatial convergence (e.g., Krugman and Venables, 1995; Venables, 1996).

As reviewed in Section 3, Liu et al. (2019)'s finding of increased airport traffic disparity in China provides indirect evidence on potential distributional effects on regional economic activities. When airport-HSR station linkage is not available, the HSR feeding effect is expected to be limited. Then, as HSR connectivity or accessibility increases, the observed net traffic increase at hub airports and net traffic reduction at non-hub airports may indicate an enhanced siphon effect on economic activities as HSR improves accessibility to the cities (though not the airports), and this shift of economic activities further affects local air travel demand. Among airports with airport-HSR station linkage, although the increased disparity in airport traffic at hub vs. non-hub airports is also observed, it is difficult to argue for a strengthened siphon effect even for the air transport sector alone, since the traffic change at non-hub airports seems to be insignificant (if any).

Since studies on the distributional effect of HSR are still rare (and developing) in the context of air transport and so one should be very cautious on the interpretation of the results (for instance, as indicated earlier, traffic reduction can also be simply attributed to the HSR substitution effect), we focus on direct empirical evidence on economic activities. Table 3 lists several recent empirical or case-study papers, their measures of economic activities, context, and main findings. In addition to Table 3, one recent report, The World Bank (2014), provided a comprehensive review on earlier, ex-post studies in the context of France, Spain, Germany, UK, and Japan. Table 4 summarizes the report's findings based on a review of studies not included in Table 3.

[Insert Table 3 here.]

[Insert Table 4 here.]

Our review of papers in Tables 3 and 4 reveals mixed results. Some papers claim that increased disparity is observed after the introduction of HSR, or that HSR is not effective in reducing spatial inequality (e.g., Chen and Haynes, 2015a; Chen and Haynes, 2017; Qin, 2017; Sasaki et al., 1997). Quite a few studies find that HSR facilitates second-and-third-tier cities to grow and hence help regional economies to achieve convergence (e.g., Bonnafous, 1987; Chen and Haynes, 2015b; Zheng and Kahn, 2013). Based on China's latest national railway network planning proposal (which was mentioned in the introduction), Xu et al. (2018) computed the connectivity and accessibility indices of the Chinese HSR network in different time periods. They found that at the early stage of HSR development, there is strong spatial disparity in HSR accessibility, but the mid/long-term plan suggests a more balanced development by 2030. On the other hand, Cheng et al. (2015) compared the patterns of employment growth between Northwest Europe and the Pearl River Delta of China, and discovered a convergent trend in the former but a divergent trend in the latter. Gutiérrez (2001) found that different conclusions could be reached if different geographical scales were chosen in the analysis.

Our view is that HSR can affect different cities through a number of channels. However, most of the studies focus only on a subset of cities, and none of the studies decompose the effect via different channels. Consequently, one can reach very different conclusions with different subjects of study and by measuring only the net effect. In other words, the seemingly opposite findings may actually complement, rather than contradict to, each other. Figure 2 illustrates different types of cities that can be influenced by an introduction of HSR, represented by the black line. Specifically, cities A, B and C are connected by HSR. Cities A and C are first-tier cities such as metropolises and provincial capitals. City B is a second- or third-tier city that is smaller and less developed than the end-node cities, such as a weak prefecture-level city or even a county as discussed in some of the papers. Dots without letters represent counties or towns nearby the cities, and they do not have direct access to HSR. City D represents other cities of similar size and level of development to those of B but do not have HSR access. Node E represents an outside area whose well-being is not under the consideration of the "domestic" cities in concern, e.g., foreign countries, but the area may have business or investment relations with the domestic cities.

[Insert Figure 2 here.]

Using Figure 2 we attempt to reconcile the findings from the literature by dividing them into two major groups: (i) cities with HSR vs. cities without HSR; and (ii) HSR-cities with different levels of development. These are done in the two sub-sections below.

### 5.1 Cities with HSR vs. cities without HSR

The first group contains findings based on a comparison of cities with HSR versus those without HSR: i.e., city D or dots without letters in Figure 2, versus cities A, B or C. This type of comparison usually reveals an increased disparity that favors areas with HSR access, especially in the case of Europe and Japan. The rationale is similar to the second mechanism mentioned in Section 3. That is, cities with HSR experience an increase in market access and hence become more attractive. For example, in Spain the Madrid-Barcelona-French border HSR line increased inequality in accessibility at national level because this corridor connects primary cities, which are already better accessed than the other cities before the introduction of the new line (Gutiérrez, 2001). Therefore, not only would people and businesses located in city D like to move to cities A, B or C, but also those located in area E, the foreign area, may prefer HSR cities to non-HSR cities, everything else being equal. This conjecture is consistent with Liu et al. (2019)'s study on Japanese airports: Regardless the hub status, airports with good airport-HSR station connection tend to enjoy traffic increase.

Empirically, the inequality has been found to increase between cities with and without HSR, i.e., cities A, B, C and city D as depicted in Figure 2. Specifically, in China's Yangtze River Delta: cities with HSR stations tend to attract more fixed asset investment and real estate investment than non-HSR cities (Li et al., 2016). In China and Spain, cities with HSR can be a lot more attractive to foreign tourists from region E (Campa et al., 2016; Chen and Haynes, 2015a). Similar positive impacts on the tourism industry are observed in Japan (Table 4). Within China's Pearl River Delta, after the introduction of Guangzhou-Shenzhen upgraded line, the two end-node megacities, especially Shenzhen, experienced substantial employment growth compared with other major non-HSR cities in the same region (Cheng et al., 2015). Furthermore, economic structures of all the other cities became more different from Guangzhou by being more specialized in certain tasks or sectors.

Small cities, counties, and towns within a major city's hinterland (dots without letters in Figure 2) tend to suffer (or achieve slower growth) once the city is connected by HSR. Although Cheng et al. (2015) found a convergent trend among major HSR cities in Northwest Europe, they did discover a higher employment growth in HSR-cities than in their non-HSR hinterlands. The economic structures tended to converge between city cores and their hinterlands, however. According to the review by The World Bank (2014), rural towns around Lille, a median-sized city connected to Paris by HSR, incurred loss. Many non-HSR towns within the commuter belt of London had weaker performance in economic strength despite increased population and residents' income. As the accessibility to the city core is enhanced, most business activities tended to move from peripheral towns to the city core in order to enjoy benefits of agglomeration. The ensuing rise in housing prices and crowdedness in city core forced more people to work and earn higher income in city core while living in peripheral areas. This phenomenon is confirmed by Campante and Yanagizawa-Drott (2018)'s study on how better long-haul international connections affect economy. They found that increased airport connections may induce spatial inequality by concentrating activities in places nearby the airports and hindering places located at distance to the airports, say above 300 miles (about 480 km) away.

Qin (2017) discovers something different in the context of China. By applying the DID method to a large sample of Chinese counties, he found that compared with counties only accessible to conventional railways without upgrade in train speed, those accessible to upgraded railway lines in 2007 suffered a reduction in GDP and fixed asset investment. Furthermore, this negative impact came from a diversion of economic activities from HSR-connected counties to HSR-connected major cities, as the latter became much better inter-connected and more attractive. However, Meng et al. (2018) applied the DID method to a similar sample of Chinese counties but found that counties with HSR achieved higher GDP than those without HSR. There are two major differences in the two studies. First, Meng et al. used more recent data (2006-2014) during which some dedicated HSR lines with much higher speed than the 2007 upgrade became available. Second, the way they set up the control groups was different. Counties without any railway service were removed in Qin (2017) but were included in Meng et al. (2018)'s control group. Since some key information about the methodology and sample is not clearly provided in Meng et al.'s study,[17] we are not able to draw much insights from comparing these two studies, but it is possible that time or the level of development plays some role here.

Overall, it seems that everything else being equal, cities with improved accessibility by HSR should enjoy better outcomes than those without accessibility improvement. This difference in accessibility improvement could cause an increased disparity in the distribution of various economic activities and may sometimes lead to task or sector specialization among cities. If a country is in the process of rapid industrialization – e.g., China – HSR may push cities to quickly specialize and achieve different economic structures. This effect may not occur in countries that are already well-developed (Cheng et al., 2015). Reduction of economic activities may occur in cities connected to HSR, but it seems only possible when major economic centers are also

[17] This is also the reason why Meng et al. (2018) is not listed in Table 3.

connected with HSR, and it might be related to the time and cities' stage of development when HSR is introduced. Detailed discussion on this is provided next in Section 5.2.

### 5.2 HSR-cities with different levels of development

The second group of studies contains findings based on comparison between the small and large cites with HSR (cities A or C vs. city B). It is true that accessibility of small cities is improved by accessing to HSR services, making them more attractive. However, similar to the third mechanism discussed in Section 3, when large cities are connected with small cities, it is not straightforward whether the large cities will siphon economic activities from the small cities or spill over some of the activities to small cities. More accurately, both may occur at the same time, leading to different net effect. In addition, HSR network layout and relative change in accessibility improvement between large and small cities may also play a role. The findings are quite mixed as only the net effect can be observed.

In fact, majority of the surveyed studies support for a dominating spillover effect or reduced inequality among connected cities to some extent, and cover a wide range of countries. Linking Paris and Lyon, the first and second largest economic centers in France, makes Lyon grow faster than Paris (Bonnafous, 1987). Earlier studies cited by The World Bank (2014) show evidence of positive impacts on regional centers (France), regional centers located in the middle of the HSR lines (Spain), and cities within 2-hour reach to megacity London (the UK). More recent studies on housing price in China also found an increase in smaller cities connected to megacities, and there seems to be a convergent trend between smaller cities and megacities (Chen and Haynes, 2015b). The World Bank (2014)'s own simulation study mentioned in Table 3 shows a positive impact on GDP by linking smaller cities to larger cities with HSR, i.e., Jilin to Changchun, and Dezhou / Jinan to Beijing / Tianjin. Even Qin (2017) found that the negative impact on fixed asset investment in HSR-connected counties diminishes as the distance to connected major cities is reduced, suggesting the existence of spillover effect on counties located close to major cities. As mentioned earlier, a recent study also suggested a convergent trend in employment growth and economic structure among major cities connected by HSR in Northwest Europe, despite that these cities have a high variety in economic and population sizes (Cheng et al., 2015). Similarly, in air transport, Campante and Yanagizawa-Drott (2018) found that air connections increase business linkage among firms and two-third of this increased firm links involving capital flowing from rich countries to middle-income countries.

Meanwhile, negative impacts are also recorded on very small cities along HSR lines, suggesting the existence of the siphon effect from very small cities to large cities. For example, small or negative impacts are found in the Le Creusot, Montceau and Montchanin region and Mâcon in the case of France (Table 4). As discussed in Section 5.1, the negative impact on Chinese HSR-counties found by Qin (2017) is said to be mainly caused by the major HSR-cities attracting activities from connected counties. However, Table 4 also records positive impacts on Montabaur and Limburg, two small towns in the middle of the HSR line linking Cologne and Frankfurt. Tian et al. (2019) studied the impact of Wuhan-Guangzhou HSR on service-sector agglomeration in seven peripheral (non-provincial capital) cities along this HSR line and found mixed results. Since those cities are linked to three provincial capitals (cores) by the same HSR line, the authors conclude that resources are spilled over from the provincial cores to the winning peripherals while at the same time resources are siphoned into the cores from the losing peripherals.

Thus, although larger and better developed regional centers seem to enjoy a certain level of spillover effects from megacities and national centers, the size of the city is not a determining factor. It seems that several factors may play a role:

(i) *Time / distance to the nearest HSR-connected major city (e.g., time / distance from city B to city A).* Positive impacts tend to be recorded for smaller cities from which one can reach the larger cities within about 2 hours via HSR. This is the case for Lyon to Paris (Bonnafous, 1987), Jilin to Changchun, Dezhou to Beijing and Tianjin, Jinan to Beijing and Tianjin (The World Bank, 2014), Lille to Paris, London and Brussels (Ureña et al., 2009), as well as the small German towns, Montabaur and Limburg, to Cologne and Frankfurt (Table 4). Although Zheng and Kahn (2013) pooled cities with and without HSR in their regression analysis and hence failed to identify the impact on cities with HSR, they confirmed the importance of distance. Specifically, they found that the positive impact of accessibility on housing price is stronger in cities 100-750 km (0.4-3 hours by a 250 km/hr HSR) away from three megacities (namely Beijing, Shanghai, and Guangzhou) than in cities located over 750 km away. Many studies also find that the positive impact will strengthen as distance decreases. For example, the estimated impact on Dezhou is stronger than Jinan while the former is 109 km closer to Beijing and Tianjin than the latter.

(ii) *The small city's level of development and ability to grow or integrate into nearby megacity's economy.* The Le Creusot, Montceau and Montchanin region and Mâcon mentioned above could reach Lyon within 40 and 20 minutes by HSR, respectively (Bonnafous, 1987), but none of them enjoyed a positive impact. Their lack of well-developed service-oriented sectors together with a small economic size may hinder their ability to take advantage of HSR to grow. As mentioned by Ureña et al. (2009), regional centers in between two or more megacities along HSR lines may attract the following activities from megacities: meetings of professionals from megacities, consultancy firms relocating to regional centers, urban tourism, scientific meetings, and seminars. Many successful cases of small regional centers in France involve specializing into certain service-related sectors (Table 4). This argument is consistent with the finding in air transport: Although many low-income cities have an excellent geographical location and hence potential to develop long-haul international connections, they are not able to turn this potential into reality since they are too poor to be worthwhile for a connection (Campante and Yanagizawa-Drott, 2018). HSR by nature is an infrastructure that provides potential for building business linkages, so it is the cities' economic conditions that determine the outcomes of connecting these cities by HSR.

(iii) *The economic condition of the larger HSR-cities*. Although we do not find any study directly discussing this issue, intuitively, if the larger city is in the earlier stage of growth, the spillover effect will be less likely to happen. In this case, the larger city itself has sufficient land, affordable living expense, and good living condition, together with better infrastructure, better public services, and more career and business opportunities. Economies of agglomeration will dominate in this case, and resources in smaller cities are more likely to be attracted to the larger city with the help of reduced transportation cost. Among other possible reasons, this might explain the different results obtained by Qin (2017) and Meng et al. (2018) mentioned in Section 5.1. The former used data up to year 2009 while the latter's data end in year 2014. During this 5-year period China's GDP almost doubled, and therefore it is possible that major HSR-cities were not developed enough to start the spillover effect in the study period chosen by Qin (2017). Now, as the megacities in China become very crowded and their housing prices increasingly unaffordable, many individuals and business are forced to relocate to nearby smaller cities which are well-connected to and probably have historically close relationship with the megacities, such as Tianjin to Beijing and Wuxi to Shanghai.

Instead of arguing for the siphon effect or spillover effect, another group of studies focuses on the possible increase in disparity due to unequal accessibility improvements caused by the HSR's network layout. Intuitively, if smaller cities experienced more accessibility improvement than do larger cities, the disparity may fall. Otherwise, if accessibility of larger cities improved more, the disparity may rise. One example of the former case is the Madrid-Barcelona-French border HSR line. Gutiérrez (2001) found that after adding this HSR corridor, inequality in accessibility along the corridor reduced, because the smallest cities on the corridor received the most accessibility improvement. Sasaki et al. (1997) claimed, with a simulation study, that expanding Japan's HSR network to remote areas would not resolve excessive agglomeration in Japan's central region, because whenever HSR is extended to remote regions, accessibilities of both the remote region and the central region increase at the same time. Ureña et al. (2009) argued that both network layout and distance to end-node cities can affect whether HSR services will stop at an intermediate city. HSR services tend to skip the intermediate city if making a stop there will raise travel time between the major end-node cities over three hours, making it infeasible for a daily return trip together with a 4-hour stay at the destination for any substantial business activity. On the other hand, if the network layout provides an alternative route with a bypass rail track such that the end-node major cities can be linked without going through the intermediate city at all, more by-pass services will be offered, reducing the number of stops made at the intermediate city. For example, there is a by-pass track outside of the city of Zaragoza in Spain such that HSR service between Madrid and Barcelona can use that by-pass track rather than go through Zaragoza's HSR station at the city center. As a result, only 25% of Madrid-Barcelona services stop at Zaragoza (Ureña et al., 2009). Moreover, if the intermediate city is a traditional regional center, its position can be threatened if small cities used to link to the regional center are now directly linked to end-node major cities by HSR. As the design and plan of HSR may intentionally favor larger cities, increased inequality in accessibility, and hence economic development, is likely to happen in this sense.

## 6. Concluding Remarks

This paper has reviewed studies on the impacts of air-HSR competition on airlines, focusing on the overall effects of parallel HSR services on passengers' mode choice as well as on airlines' traffic, fares, flight frequency, service quality and market power. The modal complementarity and air-HSR intermodal services, together with the network feature of airline business, are also examined. The paper has further reviewed theoretical and empirical findings on the impacts of HSR on airports and regional economies. We found, among others, that the impact of HSR on regional economy shares some similarity to the impact on airport traffic (except for the air-HSR substitution effect). Both involve a number of mechanisms that probably are working simultaneously, and it is hard to empirically identify and decompose the impacts of individual mechanisms. As a result, the net effect is unclear. Things can get even more complicated when several major cities and medium-sized cities are in picture, with various counties and towns in their hinterlands. Moreover, the scale of study also plays a role. One may observe a convergent trend in economic development with higher (aggregate) level data, but this may not be true at lower levels. For example, with provincial-level data, Chen and Haynes (2017) found that railway development can help less-developed provinces in China to catch up with the developed eastern coastal regions. However, the disparity within each less-developed province can be significantly higher than the disparity at the national level. Having this in mind, it is not surprising that different empirical results are present, due to the limitations of empirical tools and data as well as various endogenous problems.

We further found that current empirical findings cannot rule out the existence of siphon effect, since increased economic disparity upon the introduction of HSR services is observed in many cases. In sum, the disparity tends to increase between cities with and without HSR. However, between major and small cities linked by HSR services, it seems that the disparity could increase or decrease depending on the status of the major cities, the status of the small cities, and the distance between the small cities and the major cities. Cities with strong economic development are seldom disadvatanged by linking to megacities with HSR. The attractiveness of megacities may fall once they become too large, e.g., Shanghai and Beijing (Yang and Fu, 2018). High labor costs, expensive land and efficiency loss due to crowdedness (e.g., severe road congestion), all may turn away certain activities when there is a feasible alterative location. HSR makes some smaller cities qualified to be such second-best choices since it becomes less costly to access the major city from these smaller peripheral cities. In particular, small cities may lose from HSR entries because the connected major city is quite strong in terms of attracting economic activities but not strong enough to generate the positive spillover effect to the small cities, or because the small cities are not located sufficiently close to the major city to enjoy the spillover effect (if any).

There are several other directions for future research. First, many papers conclude for a reduced regional disparity once positive impacts on smaller cities are observed. However, increased disparity is different from growth, since both the major and small cities can grow with HSR, but the former may grow faster than the latter, still leading to more disparity. We have found very few papers that directly examine the distributional effect by comparing impacts on both the large and small cities. Second, the reactions to HSR seem to vary across sectors or tasks. Some authors believe that with the help of HSR, megacities will become the centers where people meet and make deals, while activities that do not require frequent meeting of people from various places, such as manufacturing, will be relocated to peripheral cities. We do not locate any studies that investigate how resources and activities flow between affected cities. Third, although HSR tends to serve passengers, in many cases it also releases capacity for freight transport using conventional railways (Wu et al., 2014). This can indirectly affect manufacturing but has never been studied. Finally, it is worth to carry out a more complete welfare analysis of HSR-air transport interactions, both theoretically and empirically, by including the aspects mentioned above.

**Figure 1. Network structure applied in the theoretical literature**

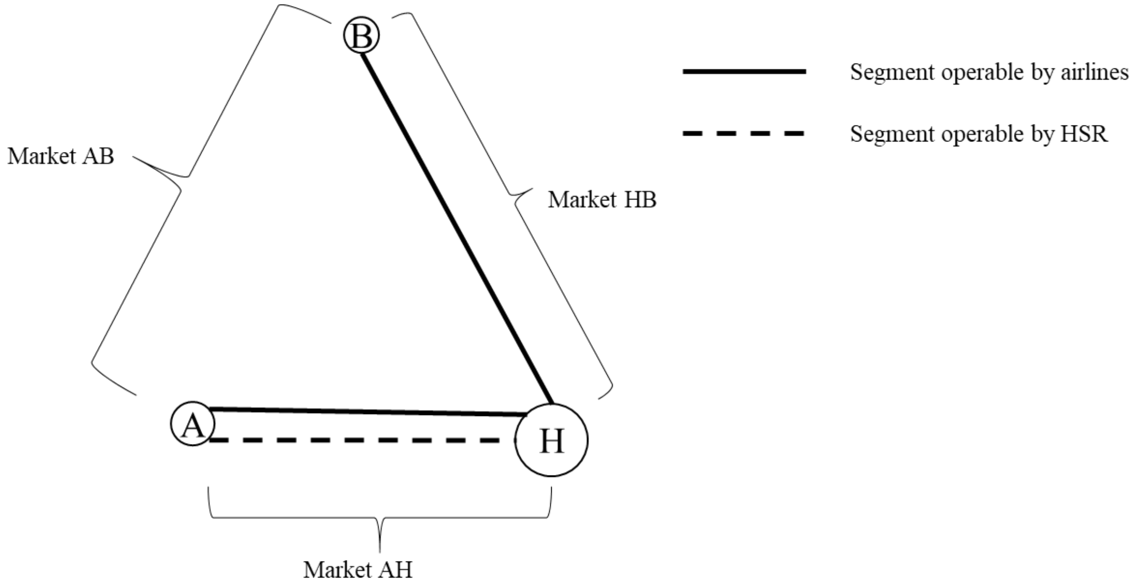


**Figure 2. Conceptual illustration on various cities/regions affected by HSR**

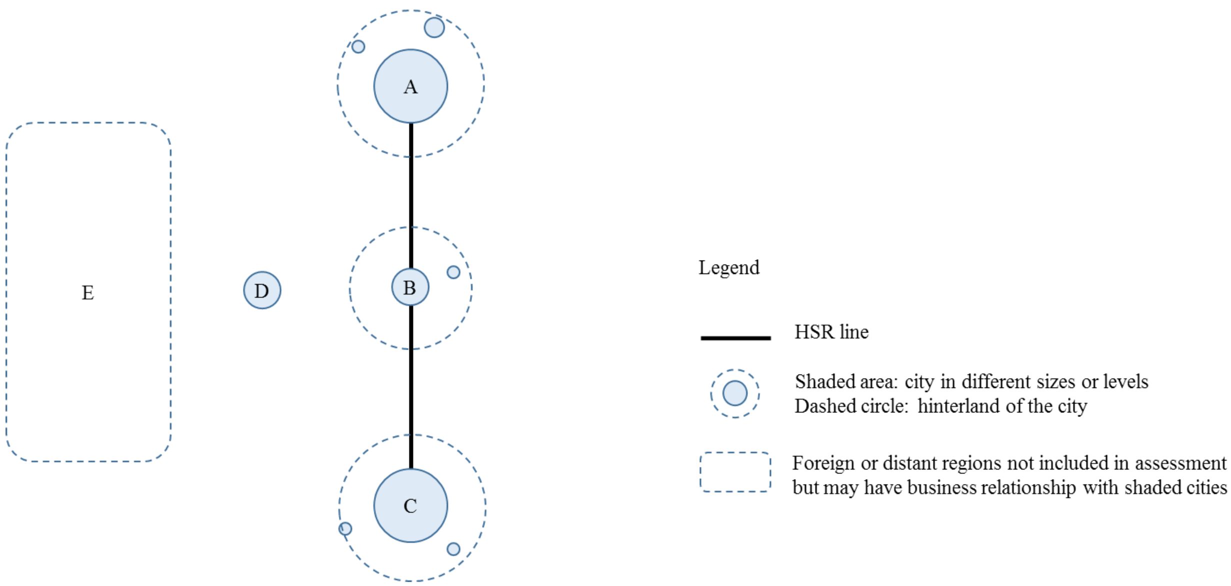

**Table 1. Summary of traffic impacts of air-HSR cooperation (with unbinding airport capacity constraint)**

| | Number of airlines / Form of cooperation | Market structure of each OD market before and after integration | | | OD market traffic impact | | | Air traffic impact on each segment | | Net air traffic effect (AH leg + HB leg) |
|---|---|---|---|---|---|---|---|---|---|---|
| | | AH market | AB market | HB market | AH market (air traffic) | AB market (air-air and air-HSR) | HB market (air traffic) | AH leg | HB leg | |
| **Socorro and Viecens (2013)** | One airline / Joint decision making | Before: Duopoly (air, HSR)<br>After: Monopoly (HSR) | Before: Monopoly (air-air)<br>After: Monopoly (air-HSR) | Before: Monopoly (air)<br>After: Monopoly (air) | Reduce to zero | Increase due to efficiency gain from air-HSR integration (HSR is assumed to be less costly to operate) | Unchanged | Reduce to zero | Increase due to increased AB passengers | May decrease if the substitution effect in AH market offsets the passenger increase in AB market; otherwise, increase |
| | Two airlines A1, A2 / Joint decision making (A2 + HSR) | Before: Duopoly (A1, HSR)<br>After: Duopoly (A1, HSR) | Before: Monopoly (A1-A1)<br>After: Duopoly (A1-A1, A2-HSR) | Before: Duopoly (A1, A2)<br>After: Duopoly (A1, A2) | Unchanged | Increase due to competition in AB market (air-air reduce, air-HSR increase) | Unchanged | Decrease as some air-air AB passengers are captured by airline 2-HSR option | Increase due to competition in AB market | Increase or decrease |
| **Jiang and Zhang (2014) / Sato and Chen (2018)** | One airline / Joint decision making | Before: Duopoly (air, HSR)<br>After: Monopoly with two differentiated products (air, HSR) | Before: Monopoly (air-air)<br>After: Monopoly with two differentiated products (air-air, air-HSR) | Before: Monopoly (air)<br>After: Monopoly (air) | Decrease due to reduced competition (Jiang and Zhang, 2014);<br>May or may not decrease (Sato and Chen, 2018) | Increase due to introduction of a differentiated air-HSR product (Jiang and Zhang, 2014); Net effect not discussed in Sate and Chen (2018) | Unchanged | Not discussed in the paper, but likely to decrease | Not discussed in the paper, but likely to increase | Not discussed in the paper |
| **Xia and Zhang (2016)** | Two airlines A1, A2 / Joint decision making (A1 + HSR) | Before: Duopoly (A1, HSR)<br>After: Monopoly with two differentiated products (A1, HSR) | Before: Three rival products (A1-A1, A1-HSR*, A2-HSR*)<br>After: Monopoly with two differentiated products (A1-A1, A1-HSR) | Before: Duopoly (A1, A2)<br>After: Duopoly (A1, A2) | Not discussed, but air fare increases while HSR fare may or may not increase, so reduction is possible | Not discussed, but both air-air fare and air-HSR fare increase so likely to decrease | Increase due to price reduction of A1 (before cooperation, a higher price is charged to discourage A1-HSR and encourage A1-A1 in AB market) | Not discussed in the paper | Not discussed in the paper | Not discussed in the paper |
| | One airline / Reducing air-rail connecting time | Before = after: Duopoly (air, HSR) | Before = after: Duopoly (air-air, air-HSR*) | Before = after: Monopoly (air) | Mixed | Increase (air-air increase, air-HSR may increase or decrease) | Decrease due to air fare increase to make air-HSR mode more expensive | Not discussed in the paper | Not discussed in the paper | Not discussed in the paper |

Note: * Airline and HSR are not integrated for air-HSR service.

## Table 2. Methodological comparison of surveyed airport-level empirical studies

| | Types of air passenger traffic studied* | Variables of interest | Market scope | Regression method | Hub vs. non-hub airport comparison | Estimation of the HSR feeding (complementary) effect |
|---|---|---|---|---|---|---|
| **Clewlow et al. (2014)** | Domestic, intra-EU, total traffic | Dummy variable indicating the existence of HSR service | France, Italy, Spain, Germany, UK (38 airports, 1995~2009) | OLS, random effect models | N | N |
| **Castillo-Manzano et al. (2015)** | Domestic traffic | HSR system-wide passenger number | Spain (Madrid airport, monthly data from January 1996 to December 2012) | Dynamic linear regression, allowing for time-varying coefficient of the interested variable | N | N |
| **Li et al. (2019b)** | Total traffic | Dummy variable indicating the existence of HSR service, number of HSR lines | China (all airports) from 2006 to 2015 | Difference-in-difference | N | N |
| **Liu et al. (2019)** | Domestic, international, and total traffic | Degree centrality, harmonic centrality, interaction with airport hub status, interaction with air-HSR linkage | China (48 airports) and Japan (16 airports), from 2007 to 2015 | Fixed effect OLS | Y | Y |
| **Qin (2018)** | Number of domestic routes operated by airlines | Not applicable, airport-level results are based on simulation instead of regression. | China (20 airports) from 2006 to 2016 | Counterfactual simulation based on difference-in-difference models | N | Y |
| **Zhang et al. (2017b)** | Flight connectivity (overall, domestic and international) | Dummy variable indicating the existence of HSR service | China (69 airports) from 2005 to 2014 | Fixed effect, Random effect, Poisson pseudo-maximum likelihood estimation | N | N |
| **Zhang et al. (2018a)** | Total traffic | Dummy variable indicating the existence of on-site HSR station at the airport, interaction with airport hub status | Central Europe (180 airports, 1997~2015), East Asia (170 airports, 2000~2016) | Difference-in-difference | Y | Y |

Note: * All the surveyed studies use passenger enplanement to measure air traffic, except Qin (2018) and Zhang et al. (2017b).

**Table 3. Summary of empirical papers on HSR's impact on redistributing economic activities**

| Paper | Measure of economic activities | Context | Main findings | Conclusion | Group [a] |
|---|---|---|---|---|---|
| **Bonnafous (1987)** | Business activities (trips, locations) | France: Compare impacts of Paris-Lyon line opened in 1981 on the Rhone-Alps (RA) region where Lyon locates (the second largest region of France) and Paris | Tourists: one-day trip tourists increased while overnight trips reduced in main cities while overnight stays in small towns increased substantially.<br>Trips for selling or buying services by RA-based firms increased substantially faster than by Paris-based firms<br>HSR is only a "bonus" in making business location decisions and plays a role only when alternative sites are similar in other aspects. | No evidence for increased disparity | 2 |
| **Campa et al. (2016)** | Number of domestic tourists, foreign tourist arrivals, tourism revenue from foreign tourists | Spain: 47 provinces from 1999 to 2015 | HSR has no impact on domestic tourists. The availability of HSR service associates with 1.3% and 1.7% more foreign tourists and revenue respectively. This impact is much smaller than the case of China in a similar study: 20% and 25% respectively. | HSR has a positive impact on attracting international tourists. | 1 |
| **Chen and Haynes (2015a)** | Foreign tourist arrivals | China: Arrival of tourists from top 21 countries of origin (1997-2012) | Increasing HSR network density or the number of HSR stations by 1% associates with 0.469% or 0.057% increase in foreign tourists, respectively. | Overall impact of HSR on international tourism industry but the weak coefficient of HSR stations may imply limited impact of the large number of small HSR stations developed for political purposes. | 1 |
| **Chen and Haynes (2015b)** | Housing value | China: 1,016 housing properties in 22 cities along the Beijing-Shanghai line, including capital or municipal cities, such as Beijing, Tianjin, Jinan, Nanjing and Shanghai | Improved HSR accessibility has a limited (maybe slightly negative) impact on housing values in capital or municipal cities, while a strong positive impact is observed in the other cities. | Housing values in the peripheral cities are getting convergent to core cities. | 2 |

| | | | | | |
|---|---|---|---|---|---|
| **Chen and Haynes (2017)** | Growth in real GDP per capita | China: Provincial-level panel data (2000-2014) | Improved railway quality and quantity have positive impact on economic growth, but the impact is much stronger in less developed regions than in developed regions. | HSR reduces regional disparity | |
| **Cheng et al. (2015)** | Employment growth, specialization pattern | Europe: Major cities in the Northwest European HSR network (Paris, Brussels, Köln, Amsterdam, Saarbrücken, Strasbourg, Frankfurt, and London) and their respective hinterlands (1999-2008)<br><br>China: Major cities in the area affected by upgraded Guangzhou-Shenzhen line (Guangzhou and Shenzhen: two end nodes; Zhuhai, Foshan, Jiangmen, Zhaoqing, Huizhou, Zhongshan: peripheral cities not linked by the line) (2003-2010) | Europe: in most of the major cities, employment growth rate is higher in the city core than in its hinterland, except Frankfurt, Paris and Saarbrücken. Growth mainly comes from public sector and finance and real estate sector. Except Saarbrücken, all the other cities show reduced level of specialization between each other. Except Frankfurt, all the hinterlands become more similar to their respective city cores.<br><br>China: The largest two cities, Guangzhou and Shenzhen, experienced largest employment growth and Shenzhen accounts for about half of the growth, but all the other cities also grow. Economic structure of Guangzhou is most similar to Shenzhen, but it is getting more than more different from other cities. | In developed Northwest Europe: interregional and intraregional convergence are observed after introduction of HSR, not only in economic performance but also in the economic structure<br><br>In the Pearl River Delta of China: after the introduction of upgraded HSR line, the growth tends to concentrate on one core city and relative to Guangzhou all the other cities become more specialized, as the region is undergoing rapid growth and industrialization. | 1, 2 |
| **Gutiérrez (2001)** | Railway accessibility | Europe: Compare levels of inequality in accessibility before and after the construction of planned Madrid-Barcelona-French border HSR line. The scope includes 88 urban agglomeration with over 300,000 population across 12 European countries. | At European level: Reduced inequality in accessibility<br>At Spanish national level: Increased inequality in accessibility, as the new line connects Madrid, Zaragoza and Barcelona which are already very well accessed at national level.<br>At the corridor level (cities along the new line): Reduced inequality in accessibility, as the smallest cities on the corridor received the most accessibility improvement | Whether disparity increases or decreases depends on the geographical scale in concern, i.e. national, HSR corridor, European level | 1, 2 |
| **Li et al. (2016)** | Flows of fixed asset investment, real estate investment and consumption | China: Cities in the Yangtze River Delta led by Shanghai, 60% of them were accessible by HSR in 2014 | Fixed asset investment and real estate investment: cities with HSR access received net inflow, while non-HSR cities experienced net outflow | Compared with cities accessible by HSR, nearby non-HSR cities become less attractive for investment but their production of non- | 1 |

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| | | | Consumption: non-HSR cities experienced net inflow while HSR cities experienced net outflow | tradable goods may benefit from indirect improvement in accessibility | |
| **Qin (2017)** | GDP, GDP per capita, fixed asset investment | China: Two waves of railway speed acceleration by upgrading existing lines into high-speed rails in 2004 and 2007; study period: 2002-2009 | In counties along the upgraded high-speed lines, 3-5% reduction in GDP and GDP per capita and 9-11% reduction in fixed asset investment. The reduction is stronger in the service sector than the manufacturing sector. Distance to major cities on the HSR line is only relevant to fixed asset investment. The farther an HSR county's distance to major HSR cities, the stronger the fixed asset reduction and the maximum reduction is reached at around 550km. | HSR seems to disadvantage counties with HSR stations compared with non-HSR counties.<br><br>Spillover effects between major cities and nearby counties is claimed to exist for fixed asset investment only. | 1, 2 |
| **Sasaki et al. (1997)** | Regional investment, product, labor supply, capital, population | Japan: ex-post facto simulation to compare current case with five hypothetical scenarios in introducing HSR lines. Compare share of economic activities among north, south and central regions of the country. | Network layout and where to improve accessibility are more at issue than the total length of HSR network. Excessive agglomeration in the central developed region cannot be resolved by extending HSR to remote regions, because improving accessibility to the remote region will at the same time improve accessibility at the developed central region which already have good access with existing HSR lines. | HSR network expansion can promote some regional dispersion, but the effect is very limited even with a very extensive network. | 2 |
| **The World Bank (2014)** | Site selection of enterprises | China: Impact of Changchun-Jilin intercity railway on Jilin (111 km away from Changchun); impact of Beijing-Shanghai HSR line on Jinan (301km away from Tianjin, 406km away from Beijing and 912km away from Shanghai) and Dezhou (192 km away from Tianjin, 314km away from Beijing and 1004 km away from Shanghai). | The Beijing-Shanghai HSR contributes to 0.55% of GDP in Jinan and 1.03% of GDP in Dezhou. Changchun-Jilin line contributes to 0.64% of GDP in Jilin.<br>Interviews on 45 enterprises in Jinan, Tianjin, Changchun and Jilin, in May 2013 suggest that at that time HSR has low influence on firms' site selection. | HSR brings agglomeration benefits and increases urban economic mass (in smaller cities), but it seems not the critical factor influencing firms' site selection decisions. | 2 |
| **Tian et al. (2019)** | Service-sector agglomeration | China: Compare actual and counterfactual service-sector | Peripheral cities along the line on average experienced a 9.44% increase in service-sector | The Wuhan-Guangzhou HSR line has both spillover effect | 2 |

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| | measured by location entropy | agglomeration indexes of seven peripheral cities along the Wuhan-Guangzhou HSR line launched in 2010. Provincial capital cities were excluded in the study. | agglomeration after the launch of HSR, but the impacts are heterogeneous across cities. Some cities experienced a reduction while other experienced an increase in service-sector agglomeration. | and "siphon" effect on non-capital cities along the line. | |
| **Ureña et al. (2009)** | (Qualitative) Share of inter-megacity services which stop at big intermediate cities, HSR passenger traffic between intermediate cities and end-node megacities | France and Spain: Case study on three big intermediate cities along HSR corridors which link major metropolises at two ends: Cordoba (1h46m to Madrid, 45m to Seville, and 57m to Malaga), Zaragoza (1h26m to Madrid and 1h39m to Barcelona), and Lille (1h20m to London, 1h02m to Paris, and 34m to Brussels) | Both network layout (ability to link megacities without passing through intermediate cities) and time flexibility affect the chance of stopping at intermediate cites. Almost half of the inter-megacity passengers stop at intermediate cities. Three types of megacity activities attracted to intermediate cities: meetings of professionals from end-node megacities, consultancy firms relocating to intermediate cities, urban tourism, scientific meetings and seminars<br>Cordoba's role as a regional center was enhanced while the other two's regional position could be weakened because small cites traditionally linked to Lille and Zaragoza are now directly linked to end-node metropolises by HSR while this is not the case for Cordoba | Improved connection between big intermediate cities and end-node metropolises makes the former more attractive to regional enterprises. On the other hand, as connection between other smaller cities and metropolises are also improved, HSR tends to enhance the position of a few major metropolises compared with big intermediate cities as regional centers in the national network of cities. | 2 |
| **Xu et al. (2018)** | HSR connectivity and accessibility | Temporal changes in HSR connectivity and accessibility of major Chinese cities as HSR network expands (2007 – 2030), including all 34 capital cities and 50 randomly selected non-capital (prefecture) cities. | The most populous cities, such as Shanghai and Beijing, are not mostly benefited. Based on the mid/long-term plans, in the future inland cities would see a substantial gain in connectivity and accessibility. | Despite high degree of spatial inequality in the early stage of HSR development, the future plan suggests a more balanced HSR connectivity and accessibility among Chinese cities in 2030. | 1, 2 |
| **Zheng and Kahn (2013)** | Housing price | China: 262 prefecture-level and above cities (2006-2010) excluding three megacities, of which 145 cities are within HSR affected area (100-750km away from the three megacities in | 59% of the increase in market potential in HSR connected cities are contributed by HSR. Market potential and housing price has a positive relationship in both cities located in the HSR affected areas and other cities, but the impact on the former is stronger than the latter. | HSR seems to foster second-tier and third-tier cities in the HSR-affected area. They conjecture that if a city does not have a potential or sign to grow by capturing the spillovers from the megacities, | |

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| | | China, namely, Shanghai, Beijing and Guangzhou) | Note: cities within the HSR-affected area are not necessary connected by HSR, while cities outside the HSR-affected area may also have HSR services. | it is less likely to be added into the HSR network. (but there is no direct evidence if more sustainable urban development can be achieved by stopping excessive growth in suburban area of megacities) | |

Note:
a. Group = 1 if the study discusses the impacts on cities with and without HSR. Group = 2 if the study discusses impacts on HSR-cities with different sizes.

**Table 4. Summary of findings on ex-post studies reviewed by The World Bank (2014)**

| Country | Impact of HSR | Group [a] |
|---|---|---|
| France | - Positive impacts on regional centers which specializing in certain industries: Lille (tertiary education, medical, banking, insurance), Le Mans (insurance), Rheims (tertiary education, online IT-based services, back office services) and Marseilles (port, regional business/service center, entertainment)<br>- Lille's local government supported by constructing office area which only attracted government-controlled / influenced companies. Small towns in rural areas without HSR stations around Lille lose<br>- Little or negative impacts on small cities: Le Creusot, Montceau, and Montchanin regions (mining), Mâcon | 1, 2 |
| Spain | - Decreased regional inequality between 1995 and 2005<br>- Positive impacts on intermediate regional centers: diversion of back office activities from large cities, growth of tourists with one-day trips (but fewer overnight stays); Passenger flows in both direction increase if major cities can be reached within 1.5 hours from the regional center | 2 |
| Germany | - Impact on Montabaur and Limburg, two small towns located in the middle of the Cologne-Frankfurt line (30 min to Cologne or Frankfurt): 1% increase in market access associates with 0.25% growth in GDP and achieved 2.7% GDP growth over four years. | 2 |
| UK | - Positive impacts on cities within a 2-hour reach to London in terms of knowledge-intensive services. Those within a 1-hour reach to London experienced population growth<br>- Towns without HSR had weaker performance. Most towns within the London commuter belt experienced: high population inflow, high income of residents but low economic strength | 1, 2 |
| Japan | - Positive correlations between population growth and HSR as well as between metropolitan growth and HSR are found but no causality has been established<br>- The extension line to Hachinohe helped the a few tourist attractions to increase visitors by 20-25% | 1 |

Note:
a. Group = 1 if the study discusses the impacts on cities with and without HSR. Group = 2 if the study discusses impacts on HSR-cities with different sizes.

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