Competition and Quality Gains: New Evidence from High-Speed Railways and Airlines

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Abstract

This study examines the causal relationship between competition and service quality using the introduction of high-speed rail (HSR) as a clean source of exogenous variation in competition faced by the intercity transportation providers. Utilizing a unique dataset containing the details of all flights departing from Beijing to 113 domestic destinations in China since January 2009, we employ a difference-in-differences approach to study the effects of high-speed rail entry on airlines' service quality (on-time performance) and to identify the channels through which competition stimulates quality. We document two main findings. First, the entry of high-speed rail creates competition for the airline industry and reduces flight delays of the affected flights. Second, the reductions in departure delay, which airlines control mostly, and taxi-in time, which destination airports control, are identified as the sources of the increase in on-time performance.

Keywords: Competition; Service Quality; Transportation; Airlines; High-speed Rail; On-time Performance

JEL Codes: D40, O4, R4, L93, L1

1 Introduction

Economists have drawn attention to the price mechanism that is the means by which consumption decisions of both consumers and firms interact to determine the allocation of scarce resources among competing uses. Yet, in most consumer markets, the quality of products or services is a determining factor for consumers to differentiate a firm among its competitors, and quality has significant effects on demand and consumer welfare (Matsa, 2011). For instance, in the transportation market, among all the competitive variables such as fares, frequency, equipment, service quality, market access, and advertising, service quality is the most highly emphasized factor (Aksoy et al., 2003). Thus, frequent flight delays or cancellations are the leading causes of dissatisfaction among travellers (US Department of Transportation, 2019)[1]. The recent boom of mobile flight tracker apps indicates that consumers take into account not only the lowest prices of flights, but also the airline's adherence to schedules (Mazzeo, 2003; Prince and Simon, 2009; Yang and Zhang, 2012).

Theory has long recognized the ways in which the entry of a strong competitor affects the pricing and quality in a given market. Although empiricists have identified quality improvement in response to competition in different industries and countries (Hörner, 2002; Haskel et al., 2007; Goolsbee and Syverson, 2008; Holmes and Schmitz Jr, 2010; Topalova and Khandelwal, 2011; Matsa, 2011; Prince and Simon, 2015), the channels through which competition stimulates quality, and the process by which competition exerts its greatest influence, remain unclear because of the lack of empirical evidence. Identifying the underlying mechanism can help incumbent market participants and regulators to improve product or service quality even in the absence of competition.

To bridge the gap in the literature, this study focuses on the connection between competition and quality in the airline industry. Among several factors to measure airlines' service quality, reliability in on-time departure and arrival is a prominent factor in shaping the traveling experience and affecting travelers' choices of mode of transportation (Mayer and Sinai, 2003; Forbes, 2008; Goolsbee and Syverson, 2008; Prince and Simon, 2015; Gayle and Yimga, 2018), and is the particular dimension of quality examined in this study. We use the introduction of high-speed rail (HSR) as a clean source of exogenous variation in competition faced by the intercity transportation providers, which is a disruptive technology in the transportation industry, to examine the causal relationship between quality and competition, and pinpoint the sources of potential improvement in airlines' on-time performance. More specifically, we employ a unique and comprehensive dataset containing the details of all flights departing from Beijing to 113 domestic destinations in China between January

[1] According to the Air Travel Consumer Reports, flight cancellations, delays, and changes have received the most air travel complaints in recent years. Source: `https://www.transportation.gov/airconsumer/air-travel-consumer-reports`.

2009 and September 2015.

The introduction of HSR has been regarded as the largest threat to the airline industry in the past decade (Adler et al., 2010; Yang and Zhang, 2012; Fu et al., 2012; Behrens and Pels, 2012; Albalate et al., 2015). HSR holds some competitive advantages over other transportation modes for three reasons. First, HSR serves as a new high-tech product labelled with speed, punctuality, convenience, safety and comfort, which substantially improves tourists' travelling experiences. Second, HSR ticket prices are more stable than airfares[2], and in China the HSR ticket price is fixed and is lower than airfare. Third, HSR is considered a pro-environment transportation mode. The greenhouse gas emissions of air transportation contribute more to global warming than other greenhouse gases at ground level[3]. Therefore, from a policy perspective, governments are encouraged to adopt the HSR in order to reduce carbon emissions. For instance, the Green New Deal[4] legislation proposed on February 7, 2019 suggests converting domestic air travel to inter-city HSR travel in the US.

The expansion of the HSR network around the world and its rising popularity as a convenient and reliable mode of transportation, especially in direct city-pair markets, have motivated a substantial amount of research on quantifying the benefits, costs, and competition effects of its introduction[5]. The existing literature has provided ample evidence that HSR takes market share away from airlines, leading to a steep drop in the frequency, airfares, and profits of airline services (Park and Ha, 2006; Adler et al., 2010; Behrens and Pels, 2012; Fu et al., 2012; Yang and Zhang, 2012; Jiang and Zhang, 2014; Albalate et al., 2015)[6].

[2]For example, in Japan, the price on Tokaido line is fixed most of the time and travelers enjoy a JPY200 discount during off-peak season; In Taiwan, travelers enjoy a limited quantity of early bird discount before the tickets are sold out; In South Korea, the HSR prices from Seoul to Daegu, Daejeon and Busan are fixed.

[3]Source: `https://www.ipcc.ch/report/aviation-and-the-global-atmosphere-2/`. According to the statistics released by United States Environmental Protection Agency, in 2016 alone, transportation accounted for 28% of total US greenhouse gas emission emissions. Of this, 12% was produced by aircraft (so 3% of the total). Source: `https://www.epa.gov/greenvehicles/fast-facts-transportation-greenhouse-gas-emissions`.

[4]The Green New Deal calls for a "10-year national mobilization". One of the primary goals is to "overhaul transportation systems in the United States to eliminate pollution and greenhouse gas emissions as much as technologically feasible", including through investment in the low-emission, affordable, and accessible public transportation: high-speed rail. Source: `https://apps.npr.org/documents/document.html?id=5729033-Green-New-Deal-FINAL`

[5]On the one hand, the introduction of HSR positively influences the agglomeration of the urban service industry (Shao et al., 2017), intercity mobility (Chen, 2012; Tierney, 2012), market integration (Zheng and Kahn, 2013), population density and employment (Levinson, 2012; Lin, 2017), and, most importantly, GDP (Ahlfeldt and Feddersen, 2017). On the other hand, some studies have revealed the misallocation of capital on HSR infrastructure (Levinson et al., 1997) and negative externalities on small counties along HSR lines (Qin, 2017).

[6]According to a World Bank Report, intercity travelers tend to choose HSR trains over road and air options (Amos et al., 2010). For instance, the supply of airplane seats on the Wuhan—Guangzhou route dropped substantially one year after the launch of HSR lines Fu et al. (2012), and all flights between Shanghai and Ningbo were canceled because of the opening of the Shanghai–Ningbo HSR line. Fu et al. (2012) show that the price of an economy class ticket for the Guangzhou–Wuhan route was reduced from RMB 800 to

However, the competition effects of HSR on the service quality of airlines has received little empirical attention because of the lack of data on the on-time performance of flights and a clear shock triggering the competition between HSR lines and airlines. Since some customer segments[7] also exhibit different degrees of sensitivity to price and quality (Rao et al., 2000), it is crucial to study non-price factors such as journal time and convenience in analyzing the effects of competition.

China is a perfect testing ground to conduct this HSR–airline competition analysis for three reasons. First, the plausibly exogenous entry of HSR lines provides fierce competition to the airline industry and enables us to examine the response of affected airlines to such competition. Second, the comprehensive data provides the opportunity to accurately measure the on-time performance. Third, given the world-class capacity and poor on-time performance of Beijing Capital International Airport (BCIA)[8] as well as China's dominant position in the HSR market, it is worthwhile studying the competition effect of HSR entry on the service quality of the airline industry to provide useful lessons for other countries when evaluating the cost and benefits of developing an HSR network (Lawrence et al., 2019)[9].

We use the entry of the Beijing–Shanghai HSR on June 30, 2011 as a plausibly exogenous shock to the airline industry. The Beijing–Shanghai HSR line is the first and only Beijing-departure HSR line linking Beijing to other cities during the sample period between January 1, 2009 and December 25, 2012 and is the most profitable HSR line in China in the mean time. The second Beijing-departure HSR line, named Beijing–Guangzhou line, began operating on December 26, 2012, 18 months after the introduction of the Beijing–Shanghai HSR line. Thus, our sample period guarantees a clean test free of other Beijing-departure HSR shocks, and covers long pre- and post-HSR time windows. Besides, focusing on the Beijing–Shanghai HSR line helps to address the non-random treatment bias. The gradual expansion of China's HSR network[10] links most major Chinese cities sequentially (see Table A1 in the Appendix), allowing the treatment and control flights to enter the estimation in a quasi-experimental manner. For instance, both the Beijing-Shanghai line and the Beijing-Guangzhou line were planed and initiated in the same year, but the former line began operating 18 months earlier than the latter one only because the length and difficulty of construction work is greater for the latter one. These attributes of Beijing–Shanghai HSR line facilitate a credible empirical

around RMB 400 one year after the launch of the HSR.

[7]Although airline companies try to promote sales by reducing prices, travelers, especially business travelers, still prefer the option of HSR trains (Behrens and Pels, 2012; ASIA and REGION, 2014).

[8]Source: `https://www.flightstats.com/company/monthly-performance-reports/airlines/`

[9]In the latest report released by *WorldBank*, China's HSR development has been seen extremely important lessons and practices for other countries that may be considering high-speed rail investments. Source: `https://www.worldbank.org/en/news/press-release/2019/07/08/chinas-experience-with-high-speed-rail-offers-lessons-for-other-countries`

[10]Source: `https://www.travelchinaguide.com/china-trains/high-speed/rail-network.htm`

analysis of the causal impact of HSR opening on the affected flights.

We employ the difference-in-differences (DID) approach to establish whether a causal relation exists between competition and quality measures, and between the HSR entry and flight supply. For flight delays, we employ both individual- and aggregate-level data to compare the on-time performance of flights departing from Beijing to 11 destinations linked to the Beijing–Shanghai HSR line with that of other Beijing-departure flights. The results show that the introduction of the Beijing–Shanghai HSR line leads to an average decrease of 2.54 minutes (14.51%) and 5.28 (14.47%) minutes in arrival delay and departure delay, respectively, and our findings survive a variety of robustness and falsification tests that support the causal inference. Moreover, the treatment and control groups exhibit parallel trends in the pre-treatment months in the analysis, which supports the underlying identification assumption of a parallel trend. We also reveal that the HSR entry leads to a 19% decrease in the number of treatment flights, suggesting that the entry of HSR could lead to a proportional decrease in greenhouse gases emissions from air travel on the routes with HSR and offer significantly large environmental benefit.

Moreover, to rule out the possibility that airlines manipulate their on-time performance by lengthening the scheduled duration (the scheduled arrival time minus the scheduled departure time) to mitigate expected delays (Mayer and Sinai, 2003; Prince and Simon, 2015), we use *scheduled duration* as an alternative outcome variable and find the treatment effects to be non-significant, suggesting that the airlines did not attempt to hide the problem of flight delays for treatment flights by extending the scheduled duration. We also include two additional measures of on-time performance, *Actual Travel Time* and *Excessive Travel Time*, both of which are unlikely to be affected by airline scheduling (Mayer and Sinai, 2003; Prince and Simon, 2015). In all cases, the on-time performance of treatment flights improves more than that of control flights in the post-HSR period.

Furthermore, if omitted factors are driving the introduction of HSR and flight delays simultaneously, then any correlation between them could be spurious. We address the potential endogeneity concern by including route-year-month fixed effects and airline-year-month fixed effects to extract the effects of opening the Beijing–Shanghai HSR line from the simultaneous effects at the route-level (or destination-level) and airline-level shocks. In addition, to address the possibility that flight-specific shocks might also affect service quality and to reduce the bias in the case that flight number was changed or canceled as well as the issue related to outliers, we aggregate the individual-flight level data at the airline-route-month level. Consistent with the individual-flight level regressions, the treatment effects in the airline-route-month level regressions are consistent with the baseline results, with similar magnitudes.

Notably, the government's decision to introduce HSR is based on economic (Ahlfeldt and

Feddersen, 2017), strategic (Shao et al., 2017), and lobbying (Albalate and Fageda, 2016) considerations rather than the on-time performance of airlines in a region; therefore, the reverse causality issue is less of a concern. We address the non-random treatment concern by comparing the treatment group that consists of flights to 11 cities along the Beijing-Shanghai line with a new control group that consists of flights to nine cities along the Beijing-Guangzhou line, which makes a more valid comparison between the treatment and control groups. In particular, the Beijing–Shanghai HSR and Beijing–Guangzhou HSR lines were both initiated by the central government in 2008; however, the latter finished construction 18 months after the opening of the Beijing–Shanghai HSR line[11]. The results of the analysis show that the treatment effects remain economically negative and statistically significant, suggesting that our competition argument is not threatened by the non-random treatment issue. Moreover, we conduct a quantile estimation to examine whether the treatment effect we document is driven by some specific flights. All quantiles show significant responses to HSR and flights with poorer on-time performance are more responsive to the entry of HSR.

To identify which area of air travel has the greatest potential for the improvement and examine the ways in which airline and airports can contribute to, we investigate the responses of *departure delay* (time under the control of airlines) and *actual duration* (time under the control of airports) to the HSR entry[12]. HSR entry leads to an average reduction in departure delay by 5.28 minutes, which exhibits the largest decline among all components in the flight duration, implying that the reduction in departure delay is the major source of improvement in on-time performance. Moreover, the taxi-in time at the destination airport reduces by 1.39 minutes on average, providing some suggestive evidence that the destination airports also strive to optimize the usage of the runway resources in the post-HSR period.

We also conduct several robustness checks to test alternative explanations. First, We conduct two subsample tests that focus on flights in the holiday period and flights exist both before and after the HSR entry to assess the concern that the customer churn in airline travel leads to a decrease in the departure delay. We also show that military/air traffic control, delayed previous flights, and flight rescheduling do not threat our identification strategy. Moreover, the placebo tests using an artificial treatment group and an artificial treatment date reveal that the effects of HSR competition are not caused by the characteristics of HSR

[11]Both the Beijing–Shanghai HSR and the Beijing–Guangzhou HSR lines are part of the "Four Vertical and Four Horizontal" medium- and long-term plan of the HSR network in China and construction work began in 2008. Since the length of the Beijing–Guangzhou HSR line is 2,298 km, which is 1.74 times that of the Beijing–Shanghai HSR line (1,318 km), the construction of the Beijing–Guangzhou HSR line took longer, and the Beijing–Guangzhou HSR was put into use 18 months after the opening of the Beijing–Shanghai HSR line. Source: `https://www.travelchinaguide.com/china-trains/high-speed/rail-network.htm`

[12]As illustrated in the flowchart in Figure 2, the *departure delay* is calculated as the time spent before leaving the gate (the actual departure time minus the scheduled departure time) and the *actual duration* consists of the taxi-out time (time spent on the departure runway), airtime, and taxi-in time (time spent on the arrival runway).

destinations, airline industry cycle, or broader HSR network plan.

The results of the heterogeneity tests suggest that non-hub airlines and flights on short to medium routes (air distance within 1,200 km) are more responsive to HSR entry than their respective counter-parties. Moreover, to generalize our results, we extend the sample period to September 2015 to include the introductions of another 19 HSR lines[13] and find consistent results. Finally, we conduct a simple back-of-the-envelope calculation of the benefit change due to decreased delays in response to the HSR entry. The lower-band benefits of time saving for air travelers on the affected round-way flights flying from Beijing to the 33 HSR cities between June 30, 2011 and September 30, 2015 is estimated at around CNY 3.34 billion, excluding passengers who switch from airplanes to high-speed railways.

The remainder of the paper is organized as follows. Section 2 provides some background on the HSR network and airline delays in China and discusses the related literature. Section 3 describes the dataset. Section 4 presents an illustrative framework to understand travellers' transportation mode choices. Section 5 details the empirical specifications and identification strategy. Section 6 presents the core results and additional tests. Section 7 provides a back-of-the-envelope calculation for the improvement in on-time performance. The conclusion follows in Section 8.

2 Background and Literature

2.1 Introduction of the HSR in China

After 20 years of development and expansion, China's high-speed railways, which are designed for speeds of 250 to 350 kph (155 to 217 mph), have become the largest and most extensively used HSR network in the world. Zhou et al. (2018) review the development of the HSR network over time. As of mid-2018, China's HSR network had expanded to 29 provinces, reaching approximately 27,000 km (17,000 miles) in total length and accounting for about two-thirds of the world's HSR tracks in commercial service. The medium-term plan[14] of the Chinese government is to expand the HSR network to 38,000 km (24,000 miles) by 2025. Based on a network plan of "eight vertical and eight horizontal," Beijing is regarded as the most important starting point of the vertical lines[15].

[13]Table A1 in the Appendix summarizes the opening dates of all these HSR lines. Many cities were connected to Beijing following the completion of some of these new HSR lines. For instance, the Beijing–Guangzhou HSR line was launched on December 26, 2012 and the Shanghai–Kunming HSR line was launched on September 14, 2014.

[14]This plan consists of the Beijing–Shanghai line, Beijing–Hong Kong line, Beijing–Harbing line, Beijing–Kunming line, Dalian–Beihai line, Baotou–Haikou line, Hohhot–Nanning line, and Lanzhou–Guangzhou line

[15]The Long-term Railway Network Plan was initiated by the central government in the early 2000s and has been updated every five years. The goal of the central government is to expand HSR lines to connect

The Beijing–Shanghai line is the first medium- and long-haul Beijing-departure HSR track that links Beijing to other 26 domestic destinations[16] (see Appendix Table A1). Among the 26 destinations, only 11 are linked with Beijing by non-stop flights. For the HSR schedule between Beijing and Shanghai, the average headway is 10 minutes, with a daily one-way frequency of 45 trips. The fastest trip between Beijing and Shanghai, namely Route G22, takes only 4 hours and 18 minutes for the 1,318 kilometres (819 mi) journey. Before June 30, 2011, the fastest train traveling from Beijing to Shanghai was a bullet train that traveled at a maximum speed of 150–200 kph and took around 13 hours. Given that a direct flight between two cities takes only two hours, train travel was therefore a much more time-consuming option before June 30, 2011. However, the opening of the Beijing–Shanghai HSR line on June 30, 2011 changed the situation completely by reducing train travel time from 13 hours to less than five hours.

According to Sachs (2010), HSR travelers spend 92% of their journey time on the train, while air travelers spend only 62% of their total journey time on the plane, highlighting the efficiency of traveling by HSR. Since punctuality, connectivity, commute time, and cost efficiency have been shown to be the most important determinants for travelers' choice of transport mode, the new Beijing–Shanghai HSR line imposes fierce competition on flights linking Beijing and the 11 HSR destinations.

2.2 Flight Delays

The Chinese airline industry has experienced tremendous growth in the past 30 years. According to a report by the Civil Aviation Administration of China[17], air passenger traffic grew from 18.2 billion in 1987 to 837.8 billion in 2016. Despite this huge growth, China's airline market is still in its nascent stages. Poor operational efficiency and regulations have been widely criticized by the public and economists. According to the 2018 world airport punctuality report[18], none of China's airports is ranked in the top 20 in terms of on-time performance. BCIA, which has become the world's second busiest airport in terms of passen-

most cities sequentially. Although some cities such as Guangzhou and Changsha are not a part of the Beijing–Shanghai HSR line, they will eventually become a part of the HSR network through other HSR lines (Shao et al., 2017). As of August 1, 2018, 37 cities in China had been connected by HSR lines departing from Beijing.

[16] Spanning a distance of 117 km, the Beijing–Tianjin HSR line is the first Beijing-departure HSR to Tianjin. The Chinese government built the line to accommodate trains traveling at a maximum speed of 350 kph (217 mph), and it currently carries China Railway High-speed trains that run up to 330 kph (205 mph). However, owing to the short distance, flights are not offered for the Beijing–Tianjin route. Therefore, the introduction of the Beijing—Tianjin HSR line should not have affected the on-time performance of any medium- or long-distance flights departing from Beijing.

[17] Source: `http://www.caac.gov.cn/XXGK/XXGK/TJSJ/201702/t20170224_42760.html`.

[18] Source: `https://www.oag.com/hubfs/Free_Reports/Punctuality_League/2018/PunctualityReport2018.pdf`.

ger traffic since 2010, registered 557,167 aircraft movements (take-offs and landings) in 2012 (ranked sixth in the world). However, it has poor on-time performance for both domestic and international flights. Domestically, it ranks 44th out of China's 55 major airports in punctuality[19] as of 2017.

Specifically, BCIA sent out 286,602 flights in 2017, and only 53.7% of them departed on time (i.e., within 15 minutes of their scheduled departure times). Moreover, departure delays averaged at around 48.5 minutes[20]. By comparison, China's most punctual airport, Xining Cao Jia Bao Airport, sent out 24,077 flights in 2017 and 78.2% departed on time; departure delays averaged at around 23.4 minutes. The world's most punctual airport, Osaka International Airport, sent out 74,914 flights in 2017 and 94.7% departed on time; departure delays averaged at around 13.1 minutes. Given the coexistence of BCIA's world-class capacity and poor on-time performance, it is thus worthwhile studying the causal relationship between competition and quality changes.

2.3 Related Literature

This study adds to the literature that examines the causal effects of competition on quality and productivity. While consensus has been reached on the effects of competition on pricing behavior[21], the influence of competition on the non-price dimension remains inconclusive both theoretically (Spence, 1975; Riordan, 1986; Hörner, 2002) and empirically (Hoxby, 2000; Schmitz Jr, 2005; Goolsbee and Syverson, 2008; Matsa, 2011). For example, Schmitz Jr (2005) and Matsa (2011) present the positive effects of competition on productivity and product quality, while Gal-Or (1983) suggests a negative relationship. Holmes and Schmitz Jr (2010) review the effects of competition on productivity and highlight two challenges. First, the definition and sources of competition must be clear. Second, the mechanism through which competition influences productivity should be identified. We contribute to this strand of the literature by analyzing the variation in competition from a clean source and by identifying an accurate mechanism for the improvement in airline service quality.

This study also complements the literature on airline competition. An extensive amount of empirical work has proven that competition in the airline industry improves the on-time performance of flights (Mazzeo, 2003; Rupp et al., 2006; Prince and Simon, 2009, 2015; Greenfield, 2014; Goolsbee and Syverson, 2008). To the best of our knowledge, we are the first to provide empirical evidence to show how service quality in the airline industry is

[19]The proportion of flights departing within 15 minutes of their scheduled departure time to the total number of flights in a year.

[20]This figure is calculated using the data collected from Feichangzhun. Source: `https://data.variflight.com/analytics/OTPRankingbyAirport`.

[21]Goolsbee and Syverson (2008); Gerardi and Shapiro (2009); Yang and Zhang (2012); Dai et al. (2014) provide evidence that competition in the airline industry reduces airfares.

affected by competition from a disruptive technology in the transportation industry. Clear definitions of HSR competition and an airline's service quality (i.e., on-time performance) as well as the exogeneity of the shock allow us to establish causal interpretations of the competition-quality relation. Moreover, the richness of flight data enables us to pinpoint the sources of the increases in quality resulting from HSR competition. This provides guidelines for airlines, airports, and governments to better manage the airline industry and improve airline efficiency—even in the absence of HSR competition.

This study contributes to yet another strand of the literature on estimating the economic impacts of transport infrastructure projects. A large amount of literature has explored the effects of urban transportation improvements in roads (Baum-Snow, 2007; Duranton and Turner, 2011, 2012; Baum-Snow et al., 2017) and railway (Donaldson, 2018) on urban growth, urban form, congestion, and trade cost. With the rapid expansion of the HSR network globally, economists have paid close attention to the economic outcomes related to the introduction of HSR. By employing the DID approach, Lin (2017) finds that the HSR entry increases the employment and passenger flows, and Shao et al. (2017) and Ahlfeldt and Feddersen (2017) reveal that the introduction of an HSR enhances economic development. In addition, HSR has been found to positively influence intercity mobility (Chen, 2012; Tierney, 2012), market integration (Zheng and Kahn, 2013), population density, and employment (Levinson, 2012). However, some studies argue that such an introduction primarily benefits large cities as opposed to small counties (Zheng and Kahn, 2013; Qin, 2017).

A number of recent studies have examined the impacts of HSR on the airline industry, most of which focus on the market share and price response. For instance, Behrens and Pels (2012) examine the conditions under which HSR can compete fiercely with the airline industry in terms of price, access time, and service frequency, arguing that competition between HSR and airlines varies by travel purpose. Yang and Zhang (2012) show that both airfares and HSR fares decrease with the weight of welfare in the HSR's objective function, while airfares decrease and HSR fares increase in response to a rise in airport access time. In line with the competition effects of HSR on airlines revealed in France, the United Kingdom, Taiwan, Japan, and Korea (Park and Ha, 2006; Gleave, 2006; Behrens and Pels, 2012; Albalate et al., 2015), Fu et al. (2012) show that the HSR entry in China takes a large proportion of market share from airlines, particularly on short-to-medium routes linking metropolitan cities. Adler et al. (2010), Fu et al. (2012), Behrens and Pels (2012), and Yang and Zhang (2012) find that the competition between HSR lines and airlines is fiercer in medium-haul transport markets, where the travel distance is approximately 400 to 1,200 km (or a travel time of about four hours). Overall, the literature provides abundant evidence that HSR threatens the survival of airlines. This study contribute to this strand of literature by examining the impacts of China's HSR on the non-price characteristics of the airline industry and providing some policy implications for other countries considering or developing an HSR network.

3 Data and Summary Statistics

3.1 Data

Using the on-time performance data provided by a leading data company that focuses on commercial aviation, this study examines the non-price responses of airlines to the HSR entry in China. The data company is a provider of comprehensive real-time global flight data to enterprises and individuals across the travel ecosystem. Specifically, we use data on the on-time performance of all flights departing from Beijing to other domestic cities[22] between January 1, 2009 and December 25, 2012 in the baseline analysis. We also expand the study by focusing on a longer sample period from January 2009 to September 2015 to generalize the results to all affected flights.

The dataset includes most information on a flight such as flight number, scheduled departure and arrival time, actual departure and arrival time, time spent traveling from the gate to the runway (taxi-out time), time spent traveling to the gate after landing (taxi-in time), and time spent in the air (airtime). In total, our dataset comprises details of 865,967 non-stop flights scheduled by 41 airlines to 113 domestic destinations in the baseline analysis. Following Prince and Simon (2015), we define a route as a directional Beijing–destination pair for any carrier that provides non-stop services. To illustrate, we consider CA1515 departing from Beijing to Shanghai to be an example. Since we have only one departure airport, BCIA, in the data, the destination city (e.g., Shanghai) also refers to a route. China Air (CA) refers to an airline company. CA1515 refers to a flight.

In the baseline analysis, we restrict the sample period from January 1, 2009 and December 25, 2012. In particular, we drop observations before January 1, 2009 and observations after December 25, 2012 to avoid confounding factors of the opening of a new airport terminal in 2008 and of the introduction of the second Beijing-departure HSR on December 26, 2012. Because the Beijing–Shanghai HSR line is the first[23] and only Beijing-departure HSR operating during the sample period between January 1, 2009 and December 25, 2012, we can conduct clean analysis on the effect of HSR competition on airline service quality. Moreover, since the Beijing–Shanghai HSR line began operating on June 30, 2011, the sample period covers a sufficient time window to study the event of the HSR entry.

[22]Flights to cities without direct flights from Beijing are excluded in the analysis.

[23]Although the Beijing–Tianjin HSR line is the first Beijing-involved HSR line, its competition effect on the airline industry is negligible because of its short distance and the absence of air routes between these two cities.

In Figure 1, we present the 113 destinations that have non-stop flights from Beijing. The 11 destinations[24] denoted by the red train signs became reachable by the Beijing–Shanghai HSR line after June 30, 2011. Table A1 in the Appendix summarizes the HSR destinations linked to Beijing along the different HSR lines. The opening of the Beijing–Shanghai HSR line on June 30, 2011 directly affected 26 destinations. Among these 26 cities[25], only 11 cities are linked by non-stop flights with Beijing. Therefore, flights departing from Beijing to these 11 destinations along the Beijing-Shanghai line are considered to be the treatment group because they are subject to the competition pressure imposed by the introduction of the Beijing–Shanghai HSR line, and the remaining flights departing from Beijing to other 102 non-HSR cities serve as the control group.

[**Figure 1 inserted here**]

We extend our analysis by focusing on a longer sample period that ranges from January 2009 to September 2015 to conduct a generalized analysis that includes the introduction of all other Beijing-departure HSR lines such as the Beijing–Guangzhou HSR line and Tianjin–Qinhuangdao HSR line. More specifically, 18 new HSR lines operated between December 2012 and September 2015. In this period, the data are expanded to include more than 2.45 million flights and the number of treated destinations reached by Beijing-departure HSR increases from 11 to 33. In the extended sample period, the flights departing from Beijing to the destinations labelled by the train signs (including red, green, and black) belong to the treatment group, and the rest Beijing-departure flights are labelled by the blue airport signs belong to the control group.

3.2 Outcome Variables: Measures of On-time Performance

We investigate how flights in the treatment group respond to the HSR entry using different measures of on-time performance, which are commonly used in existing studies (Mayer and Sinai, 2003; Goolsbee and Syverson, 2008; Prince and Simon, 2009, 2015). We first construct two measures of on-time performance for both the arrival and the departure delays. *ArrDelay in minutes* (ADM) presents the number of minutes late (or early) a flight arrives at the gate relative to the scheduled arrival time. *ArrDelay 30 minutes* (ADD30) is a dummy equal to

[24]Changzhou, Hangzhou, Hefei, Jinan, Nanjing, Ningbo, Qingdao, Shanghai, Wenzhou, Wuxi, and Xuzhou

[25]17 cities (Langfang, Cangzhou, Dezhou, Jinan, Tai'an, Jining, Zaozhuang, Xuzhou, Suzhou (Anhui Province), Chuzhou, Nanjing, Zhenjiang, Changzhou, Wuxi, Suzhou (Jiangsu Province), Kunshan, and Shanghai) are located along the Beijing–Shanghai HSR line. While the other nine cities (Qingdao, Bengbu, Hefei, Liu'an, Hangzhou, Shaoxing, Ningbo, Quzhou, and Wenzhou) are not located along the line, they have also been linked directly to Beijing since June 30, 2011, when several already established HSR lines involving these destinations became connected to the Beijing–Shanghai HSR line at certain intersections. For instance, the Beijing–Hangzhou HSR became available on June 30, 2011 because the Beijing–Shanghai HSR line was connected to that line, which was introduced on October 26, 2010.

1 if a flight arrives at the gate at least 30 minutes late and 0 otherwise (Prince and Simon, 2015). Similarly, we construct two measures of departure delay and denote them as *DepDelay in minutes* (DDM) and *DepDelay 30 minutes* (DDD30).

Since the observed improvement in arrival delays in response to the HSR entry could be biased if airlines manipulate their on-time performance by adjusting the scheduled flight time to mitigate expected delays (Mayer and Sinai, 2003; Prince and Simon, 2015), we then construct two alternative measures of on-time performance: *Actual Travel Time (ATT)* and *Excessive Travel Time (ETT)*. *ATT* captures the time difference between the scheduled departure time and actual arrival time. *ETT* is computed as *ATT* minus the minimum feasible travel time. The minimum feasible actual travel time refers to the minimum travel time of a flight observed in a given month, and this serves as a benchmark for determining the travel time when a flight is free of any external influences such as air congestion and weather conditions. Therefore, *ETT* controls for any unobserved or observed time-varying external influences and is immune to airline scheduling conflicts.

Figure 2 provides a flowchart to illustrate the components of flight duration, which can be decomposed into two parts: the *departure delay* and *actual duration*. While the *departure delay* measures the time spent before leaving the gate, the *actual duration* includes *taxi-out time* (time spent on the departure runway, is defined as the time between the actual pushback and wheels-off), *airtime* (time spent in the air), and *taxi-in time* (time spent on the arrival runway).

[**Figure 2 inserted here**]

We also plot the distributions of *Actual Travel Time* for HSR and flights for HSR and flights to 11 cities along the Beijing-Shanghai line in Figure 3. According to the latest World Bank report[26], the punctuality rate of HSR service in China is over 98 percent for departures and over 95 percent for arrivals. Therefore, we consider the travel time invariant for HSR travel, which is denoted by the red vertical line in Figure 3. However, due to the uncertainty of weather condition, air congestion, and military control, the travel time for flights (denoted by the black lines in Figure 3) shows large variance.

[**Figure 3 inserted here**]

Table 1 reports the summary statistics of the on-time performance measures and other variables at the individual-flight level. For both treatment and control flights, the mean of *ArrDelay in minutes*, *DepDelay in minutes*, *ATT*, and *ETT*, increase by one to four minutes in the post-HSR period, while the increments of delays for the treatment group are smaller than those for the control group. The summary statistics for the aggregated airline-route-month level (12,499 airline-route-month observations) is reported in Appendix Table A2.

[**Table 1 inserted here**]

[26]Source: `https://openknowledge.worldbank.org/handle/10986/31801`

4 A Framework for Intercity Transport Mode Choice

This section presents a conceptual framework to understand the intercity transportation mode choice based on different consumer preferences and risk attitudes. Potential passengers are differentiated by three characteristics:

- θ : the value of the trip
- w : the unit cost of time
- r : risk aversion

Consider a route between Beijing and a city. A passenger has three intercity travel mode choices prior to the introduction of the HSR, and the HSR offers the fourth option:

1. ϕ : do not travel
2. s : the conventional train
3. a : flight
4. h : HSR

Each travel option $i \in \{s, a, h\}$ is characterized by (p_i, t_i) where p_i is the price and t_i is travel time. While in reality the travel time for each travel mode is likely to involve some randomness. For simplicity, we assume that the conventional train and HSR are punctual, and thus t_s and t_h are not random; however, the time for air travel is a random variable which we denote by $\tilde{t}_a$, with expectation given by t_a and variance v_a. We assume that:

Assumption 1. $t_s > t_h > t_a$; $v_s = v_h = 0 < v_a$.

That is, air travel in expectation is the fastest travel mode, followed by HRS and conventional passenger train.

Assumption 2. $p_s < p_h < p_a$.

Air travel costs more than HSR services, which in turn cost than standard fares of conventional train.

We assume the following mean-variance utility function specification regarding total traveling time. A passenger of type (θ, w, r) evaluates option i by

$$\theta - t_i w - r v_i - p_i,$$

where rv_a reflects the disutility from the uncertainty in travel time associated with air travel. Finally, we denote the joint distribution of (w, r) in the population by $G(w, r)$ with density function $g(w, r)$; and let the density distribution of θ conditional on (w, r) be denoted by $f(\theta|w, r)$.

4.1 Pre-HSR

Let us first analyze the case before the entry of HSR. For passengers with type (w, r), he/she will choose to travel if and only if

$$\theta \geq \underline{\theta}(w, r) \equiv \min\{t_s w + p_s, t_a w + rv_a + p_a\}. \tag{1}$$

Conditioning on $\theta \geq \underline{\theta}(w, r)$, a type-$(\theta, w, r)$ passenger will choose air travel if and only if

$$w \geq \underline{w}(r) \equiv \frac{v_a}{t_s - t_a} r + \frac{p_a - p_s}{t_s - t_a}.$$

Thus, the market shares for air travel and conventional train are respectively:

$$\begin{aligned} M_a(t_s, t_a, v_a; p_a, p_s) &= \int_0^{\bar{r}} \int_{\underline{w}(r)} \int_{\underline{\theta}(w,r)}^{\infty} f(\theta|w, r) g(w, r) d\theta dw dr \\ M_s(t_s, t_a, v_a; p_a, p_s) &= \int_0^{\bar{r}} \int_0^{\underline{w}(r)} \int_{\underline{\theta}(w,r)}^{\infty} f(\theta|w, r) g(w, r) d\theta dw dr \end{aligned}$$

The fraction of non-travelers is simply:

$$M_\phi(t_s, t_a, v_a; p_a, p_s) = 1 - M_a(t_s, t_a, v_a; p_a, p_s) - M_s(t_s, t_a, v_a; p_a, p_s).$$

The passengers' travel mode choices in the pre-HSR period is depicted by Figure 4.

[Figure 4 inserted here]

4.2 Post-HSR

Now let us introduce the HSR option (t_h, p_h). Suppose that the introduction of HSR also reduces (t_a, v_a) to (t_a', v_a') respectively.

Assumption 3. $t_a' < t_a, v_a' < v_a$.

First, note that the introduction of HSR will expand the passenger travel market. A passenger will travel if and only if

$$\theta \geq \underline{\theta}'(w, r) \equiv \min\{t_s w + p_s, t_h w + p_h, t_a' w + rv_a' + p_a\}. \tag{2}$$

Comparing the expressions of $\underline{\theta}'(w,r)$ in (2) and $\underline{\theta}(w,r)$ in (1), we note that there are two channels through which the passenger travel market is expanded: first, the availability of (t_h, p_h) as a travel mode could be a more attractive option for some types of passengers (as we will show below, those passengers with higher wage rate); second, the introduction of HSR leads to the improvement of the air travel option because $t'_a < t_a$, $v'_a < v_a$.

Now let us analyze how different types of consumers make their travel decisions. The comparison between options s and h are very simple. Since $v_s = v_h = 0$, it involves the comparison of

$$\min\{t_s w + p_s, t_h w + p_h\}$$

If a passenger chooses the train option, he will choose the HSR h if and only if

$$w > w^*_{sh} \equiv \frac{p_h - p_s}{t_s - t_h}.$$

That is, high wage passengers choose HSR.

For a passenger to choose to ride a conventional train, the following conditions must be satisfied:

- $\theta \geq \underline{\theta}'(w,r)$;
- he/she must have $w < w^*_{sh}$ (so he/she choose slow train over HSR) and

$$w \leq \underline{w}'_s(r) \equiv \frac{v'_a}{t_s - t'_a} r + \frac{p_a - p_s}{t_s - t'_a}.$$

  (so he/she chooses to travel by conventional train over air).

Similarly, for a passenger to choose to HSR, the following conditions must be satisfied:

- $\theta \geq \underline{\theta}'(w,r)$;
- he/she must have $w > w^*_{sh}$ (so he/she choose HSR over slow train) and

$$w \leq \underline{w}'_h(r) \equiv \frac{v'_a}{t_h - t'_a} r + \frac{p_a - p_h}{t_h - t'_a}.$$

  (so he/she chooses to travel by HSR over air).

$$\begin{aligned}\frac{v'_a}{t_s - t'_a} r + \frac{p_a - p_s}{t_s - t'_a} &= \frac{p_h - p_s}{t_s - t_h} \\ v'_a r &= \frac{p_h - p_s}{t_s - t_h}(t_s - t'_a) - (p_a - p_s) \\ \Rightarrow \quad r^*_{sa} &= \frac{\frac{p_h - p_s}{t_s - t_h}(t_s - t'_a) - (p_a - p_s)}{v'_a}\end{aligned}$$

$$\begin{aligned}\frac{v'_a}{t_h - t'_a} r + \frac{p_a - p_h}{t_h - t'_a} &= \frac{p_h - p_s}{t_s - t_h} \\ v'_a r &= \frac{p_h - p_s}{t_s - t_h}(t_h - t'_a) - (p_a - p_h) \\ r^*_{ha} &= \frac{\frac{p_h - p_s}{t_s - t_h}(t_h - t'_a) - (p_a - p_h)}{v'_a}\end{aligned}$$

It is easy to verify that

$$r^*_{sa} = r^*_{ha} = r^*$$

There are two possible cases: (Case 1): $r^* > 0.$; (Case 2): $r^* < 0$. The passengers' choices of three travel modes in the post-HSR period is depicted by Figure 5. The top figure plots the travel mode choices in Case 1 and the bottom figure plots that in Case 2.

[Figure 5 inserted here]

5 Empirical Strategies

5.1 Causal Relationship between the HSR Entry and Flight Delays

To examine the causal effects of HSR entry on the service quality of the affected flights, we employ a DID approach at individual-flight level. This approach allows us to alleviate the endogeneity concerns related to the fact that competition and service quality within an industry are not only potentially mutually dependent, but also potentially simultaneously affected by local attributes, such as economic conditions and institutional quality. We examine the effects of introducing the first Beijing-departure HSR line, the Beijing–Shanghai HSR line, on various on-time performance measures of flights, and restrict the sample period to January 1, 2009 to December 25, 2012.

The specification of the baseline analysis is as follows:

$$Delay_{i,j,d,t} = \alpha + \beta \cdot Treatment_{i,j,d} \cdot After_t + \mu_i + \delta_{hour} + \zeta_t + \epsilon_{i,j,d,t} \tag{3}$$

where $Delay_{i,j,d,t}$ is one of the delay measures for flight i of airline company j departing from Beijing to destination d on date t. The treatment group consists of flights departing from Beijing to these 11 destinations along the Beijing-Shanghai line, and the control group consists of flights departing from Beijing to other 102 domestic non-HSR cities. $After_t$ is a dummy that takes the value 1 after June 30, 2011 and 0 otherwise. β is the parameter of interest to be estimated, which captures the difference in the average post-HSR delays of a treated flight relative to the post-HSR delays of a control flight. μ_i refers to the flight fixed effect (flight number), capturing unobserved factors that may affect flight delays at the flight level. The term δ_{hour} represents the hourly fixed effects, which account for any hourly variations that may affect flight delays, such as the hourly density of departure flights. We also include the date fixed effects ζ_t to eliminate any seasonal and national trends. The standard errors are clustered at the destination level to capture the potential serial correlations in the residual error terms. Generalizing our conclusions, we extend the analysis by examining a longer period, namely January 1, 2009 to September 30, 2015. In this lengthened sample period, 22 more HSR cities are covered.

We also examine the dynamics of the on-time performance response by estimating the following model:

$$\begin{aligned} &Delay_{i,j,d,t} = \alpha + \beta_s \cdot Treatment_{i,j,d} \cdot After_s + \mu_i + \delta_{hour} + \zeta_t + \epsilon_{i,j,d,t} \\ &s = -4, -3, -2, ..., 3, 4, 5 \end{aligned} \tag{4}$$

where $After_s$ is a binary variable equal to 1 for quarter s (-4, -3, -2, ..., 3, 4, 5) before/after June 30, 2011. The coefficient β_s measures the difference in the response of on-time performance compared with the first 12 months (benchmark period 2009:01–2009:12) in our sample period between the treatment and control groups. More specifically, the coefficient β_0 measures the immediate response in on-time performance during the HSR introduction quarter. The coefficients $\beta_1, \ldots, \beta_5$ measure the responses in the first quarter, ... , and fifth quarter after the HSR introduction quarter, respectively. Similarly, coefficients $\beta_{-1}, \ldots, \beta_{-4}$ capture the difference in trends in on-time performance change between the treatment and control groups in each of the four pre-treatment quarters.

It is worth noting that shocks specific to a single flight might affect on-time performance, which could in turn contaminate our estimations. For instance, if the ID number of a flight was deleted or changed during our sample period (e.g., flight CA0000 (Beijing–Shanghai) changed its identification to CA0123 (Beijing–Shanghai)), then a comparison of the flight delays before and after the introduction of the HSR could be biased, as we would not be focusing on the same flight before and after the event. To deal with such a possible bias at the flight level, we aggregate our individual-flight level data at the airline-route-month level[27] and conduct the DID estimations at the airline-route-month level using the following specification:

$$Delay_{j,d,m} = \alpha + \beta \cdot Treatment_{j,d} \cdot After_m + \theta_j + \eta_d + \gamma_m + \epsilon_{j,d,m} \quad (5)$$

where $Delay_{j,d,m}$ is a measure of the average delay for airline company j departing from Beijing to destination d in month m. In the aggregate-level regressions, we control for airline fixed effects, route (destination) fixed effects, and year-month fixed effects. We estimate weighted least squares (WLS) models using the number of flights on each airline route in each month as the weight in the respective cells (Prince and Simon, 2009, 2015). This enables us to produce the same estimates as those extracted from performing ordinary least squares on the disaggregated flight-level data.

5.2 Identification Strategies for Non-random Treatment

Since the placement of destinations on the HSR line as well as the order of HSR construction depends on numerous factors such as the local economy, industry distribution, and geographic characteristics, the estimation effects discussed above are subject to endogeneity bias due to the non-random treatment[28]. To address the non-random treatment issue and to ensure a valid comparison between the treatment and control groups, we create a new control group consisting of only nine destinations[29] (indicated by the green train signs in Figure 1) along the Beijing–Guangzhou HSR line.

Cities located along the Beijing–Shanghai and Beijing–Guangzhou HSR lines are in great comparability. First, both the Beijing–Shanghai and Beijing–Guangzhou HSR lines were parts of the "Four Vertical and Four Horizontal" medium- and long-term HSR network plan[30], which was initiated in 2004. Second, the construction of both lines commenced at the same time in October 2008, while the construction of the Beijing–Guangzhou line took more time and finished 18 months after the opening of the Beijing–Shanghai line because the Beijing–Guangzhou line spans 2,298 km, which is 0.5 times longer than the Beijing–Shanghai line (1,318 km). Moreover, Appendix Table A3 shows the comparison of the key macroeconomic variables, such as population, income, GDP, and number of flights in the treatment and control cities. After constructing new control groups, the differences between the treatment and control cities in all macroeconomic variables become economically and

[27]For instance, although flight CA0000 (Beijing–Shanghai) changed its identification to CA0123 (Beijing–Shanghai), we can still examine the variations at the airline-route-month (i.e., CA-Beijing–Shanghai-month) level before and after the entry of the HSR

[28]Many of the destinations in the control group, such as Yulin (a third-tier city), are not comparable to HSR destinations such as Shanghai (a first-tier city).

[29]Zhengzhou, Taiyuan, Luoyang, Wuhan, Yichang, Changsha, Xian, Guangzhou, and Shenzhen.

[30]Source: `https://www.travelchinaguide.com/china-trains/high-speed/rail-network.htm`

statistically indistinguishable from zero, suggesting that the nine cities of the control group are more comparable to the 11 cities of the treatment group. We also avoid the problems presented in our original DID analysis by keeping the number of treated subjects similar to the number of control subjects. Thus, the non-random placement problem is much less of a concern when we compare flights departing to 11 cities along the Beijing–Shanghai line with flights departing to the nine control cities on the Beijing–Guangzhou line in the subsample analysis.

5.3 The Effect of HSR on Supply of Flights

We then test to what extent the entry of HSR draws travelers away from air travel by focusing on the effect of HSR entry on supply of flights at three levels: flight-month, airline-route-month, and route-month. The specifications are given as follows:

$$Y_{i,m} = \alpha + \beta \cdot Treatment_i \cdot After_m + \mu_i + \gamma_m + \epsilon_{i,m} \quad (6)$$

$$Y_{j,d,m} = \alpha + \beta \cdot Treatment_{j,d} \cdot After_m + \theta_j + \eta_d + \gamma_m + \epsilon_{j,d,m} \quad (7)$$

$$Y_{d,m} = \alpha + \beta \cdot Treatment_d \cdot After_m + \eta_d + \gamma_m + \epsilon_{d,m} \quad (8)$$

where i, j, d, and m index the flight number, airline, route (or destination), and year-month, respectively. $Y_{i,m}$, $Y_{j,d,m}$, and $Y_{d,m}$ represent the number of flights in flight-month cells, airline-route-month cells, and route-month cells, respectively. $Treatment_i$, $Treatment_{j,d}$, and $Treatment_d$ equal 1 if flight, airline-route, and route belong to the 11 HSR cities, respectively. Flight fixed effect[31] μ_i is included in Equation (6); airline fixed effect θ_j and route (or destination) fixed effect η_d are included in Equation (7); and route (or destination) fixed effect η_d is included in Equation (8). Year-month fixed effects γ_m are included in three equations.

6 Empirical Results

6.1 Core Results

Table 2 presents the main results for Equation (3). We test the difference in the on-time performance of treated and control flights before and after the introduction of HSR from

[31] μ_i refers to the flight fixed effect (flight number), capturing unobserved factors that may affect flight delays at the flight level, at the airline company level, and at the destination (route) level. For example, CA1831 departs from Beijing to Shanghai. Therefore, controlling for the flight fixed effect (i.e., CA1831) actually absorbs the unobserved characteristics across flights (i.e., CA1831), across airline companies (i.e., CA), and across destinations (i.e., Shanghai).

Jan 1, 2009 to December 25, 2012.

The estimated coefficients on $Treatment * After$ are consistently significantly negative in all columns. The findings suggest that flights experiencing competition from the HSR entry improve their quality by reducing delays to a greater extent in the post-HSR period relative to flights in the control group. Specifically, at the intensive margin (as shown in Columns 1 and 3), on average, the treatment group reduces 2.54 minutes (by 14.51%) and 5.28 minutes (by 14.47%) for their arrival delay and departure delay, respectively. At the extensive margin (as shown in Columns 2 and 4), treated flights are less likely to delay in the post-HSR period relative to control flights. The introduction of the HSR also reduces actual travel time (ATT) and excessive travel time (ETT) by 4.7 and 3.9 minutes, respectively.

[**Table 2 inserted here**]

In the dynamic analysis, we conduct a classic event study that shows the treatment effects before and after the entry of the HSR on the on-time performance of treated flights. We plot the estimated coefficients of β_s for different measures of on-time performance in Figure 6. It shows that the treated flights start responding to the introduction of HSR from the Beijing–Shanghai HSR line immediately after its introduction; and the responses persist. However, we see no systematic differences in pre-trends between treatment and control groups, which also indicates that an essential prerequisite, the parallel trend assumption, for the validity of the DID design is well supported. We also add a new interaction term, $\beta_0 \cdot Treatment \cdot Before$, into equation (3) and the estimated results are reported in Appendix Table A4. $Before$ is a binary variable equal to 1 for the 18 months (2010:01–2011:06) before the introduction of the Beijing–Shanghai HSR and 0 otherwise. The coefficient β_0 measures the difference in the response of on-time performance compared with the first 12 months (benchmark period 2009:01–2009:12) in our sample period between the treatment and control groups in the 18 pre-treatment months. We find the estimated coefficients of the pre-treatment period variable $Treatment \cdot Before$ are both economically and statistically insignificant, which suggest that there were no differences in the changes of on-time performance between treated and control flights before the entry of the Beijing–Shanghai HSR line.

[**Figure 6 inserted here**]

Nevertheless, the Chinese government's decision to introduce high-speed railways was dependent on several factors including economic (Ahlfeldt and Feddersen, 2017) and strategic considerations (Shao et al., 2017) as well as lobbying (Albalate and Fageda, 2016). This is not a concern provided the factors are independent of individual-flight level delays. However, if any factors that drive the introduction of the HSR and individual-flight level delays are simultaneously omitted, then any correlation between them could be spurious. To address any omitted factors at the route (or destination) and airline (or firm) level, we include route fixed effects interacted with the year-month fixed effects and airline fixed effects interacted with the year-month fixed effects. The results are reported in Appendix Table A5 and show great consistency with the baseline results in Table 2.

Furthermore, results in Table 3 account for the possibility of the cancellation, deletion, and change of flights by aggregating the individual-flight level data into airline-route-month cells. The coefficients of the interaction term are consistently negative and significant in all columns and the average arrival delays of treated flights decrease by 3.4 minutes more than that of control flights in the post-HSR period. This finding suggests that our baseline results are robust to flight-level shocks.

[**Table 3 inserted here**]

To address the non-random selection of treatment group discussed in Section 5.2, we conduct a cleaner test by comparing the on-time performance of the flights to the 11 cities along the the Beijing-Shanghai line (treatment group) with the on-time performance of the flights to the nine cities along the Beijing-Guangzhou line (control group). Table 4 reports the estimation results. The treatment effects β in Table 4 are statistically different from zero in all columns, suggesting that our competition argument is not threatened by the endogeneity of sample selection. Specifically, on-time performance improves by 2.2 to 3.6 minutes for different outcome variables.

[**Table 4 inserted here**]

As a check on the robustness of our findings, we examine whether our results were sensitive to the flight distance between cities. In particular, we drop Guangzhou and Shenzhen in the control cities to ensure that flights departing from Beijing to both treatment and control cities share similar distance[32]. We also drop flights to the other terminal city, Shanghai, from the treatment group so that all flights are on the intermediate cities along the lines. We repeat the regressions and find the results robust (see Appendix Table A6).

Moreover, the standard linear regressions estimate only the average effect and might hide effects at different quantiles of the distribution. To examine whether the treatment effect we document is driven by some specific flights, we conduct a quantile estimation (Koenker and Hallock, 2001). The results are presented in Figure 7. We find that the on-time performance, for both arrival and departure measures, show significant responses to the HSR entry in all quantiles, and that the responses are larger in the upper quantile than in the lower quantile, suggesting that flights with poorer on-time performance are more responsive to the entry of HSR.

[**Figure 7 inserted here**]

[32] After dropping Guangzhou and Shenzhen, Changsha (1631km from Beijing) becomes the farthest control city, which has a similar distance with the farthest city, Wenzhou (1673km from Beijing).

6.2 The Sources of Improved On-time Performance

The results in Tables 2 to 4 suggest that the airline industry improves its on-time performance in response to the HSR entry. It is worthwhile identifying which area of air travel has the greatest potential for on-time performance improvement and examining the ways in which airline and airports can contribute to. In this section, we investigate the sources of reduced delays more in depth and assess the robustness of the results. The results are presented in Table 5. In particular, we decompose *Actual Travel Time* (actual arrival time minus scheduled departure time) into two parts: *departure delay* and *actual duration* (see Section 3.2 for more details and Figure 2 for a graphic illustration).

As shown in column 1 of Table 5, *departure delay*, which is calculated as the time difference between actual departure time and schedule departure time, decreases by 5.28 minutes in response to the HSR entry. Departure delay is mostly under airlines' control because it measures the delay before leaving the gate (Prince and Simon, 2009). Airlines could reduce the departure delay by accelerating the check-in and boarding process and by training the aircrews. The coefficient is negative and statistically significant at the 1% level. This finding suggests that the reduction in the departure delay might be the source of improvement in the on-time performance of treated flights after the HSR introduction.

Column 2 of Table 5 test the the competition effect of the HSR entry on *actual duration*. Although the coefficient of the interaction terms in column 2 is statistically insignificant, the components of actual duration (*taxi-out time*, *air time*, and *taxi-in time*), as shown in columns 3 to 5, provide some interesting results. More specifically, while the coefficient on *taxi-out time* bears no significance, we find statistically significant positive effects on *air time* and negative effects on *taxi-in time*.

[Table 5 inserted here]

As Prince and Simon (2009) state, runway time is likely to be substantially affected by both the departure and the arrival airports. The coefficient in column 3 is statistically indifferent from zero, suggesting that the HSR entry does not affect taxi-out time at the departure airport. Thus, the possible composition change of allocating flights from the treatment to the control flights at the departure airport does not threaten the baseline results because the departure airport congestion should affect treatment and control flights similarly[33]. However, column 4 shows that the introduction of the HSR reduces taxi-in time at an significant magnitude (1.39 minutes on average) at the arriving airport, providing some suggestive evidence that the airports strive to optimize the usage of the runway resources in the post-HSR period.

[33] Appendix Figure A1 plots the distribution of flights per hour at BCIA before and after the HSR entry. We observe a similar number of treatment and control flights depart throughout the day in the post-HSR period, especially in the peak hours (1am, 6am, 7am, 9am, 10am and 10–11pm).

Airlines may allocate flights from treatment routes to control routes, which subsequently causes congestion in the control routes and leads to the decrease of on-time performance for the control flights, then the improvement in on-time performance simply reflects a composition change between treatment and control groups rather than an increase in quality. Air time usually depends on air corridor congestion, wind direction/speed, and some other unpredictable factors (Prince and Simon, 2009). The coefficient in column 5 shows that the HSR entry causes the air time of the treatment flights to increase by 1.74 minutes on average. Although we cannot rule out the possibility that airlines allocating flights from the routes with HSR to routes without, our results lend strong support that the air corridor is less congested in the routes without HSR in the post period, relative to that in the routes with HSR.

In addition, to address the concern that reduction in arrival delay might be the result of a prolonged scheduled duration instead of actual improved quality because airlines can manipulate a flight's on-time performance by prolonging the scheduled duration (Mayer and Sinai, 2003; Prince and Simon, 2015), column 6 of Table 5 reports the results using the *scheduled duration* as the dependent variable. We find that the coefficient on β is not statistically significant from zero, implying that the airlines of treatment group do not adjust the scheduled duration to generate a seeming improvement in on-time performance.

To sum up, the competition from HSR urges airlines to improve on-time performance before leaving the gate and drives destination airports to reduce runway congestion, and subsequently reduces arrival delays. That is, we identify the reduction in departure delays and taxi-in time as the sources of improvement in the on-time performance of treated flights in the post-HSR period.

6.3 Supply Changes

Table 6 reports the results of estimating Equations (6) to (8). It shows that the coefficients of the interaction terms are economically negative and statistically significant, suggesting that the supply of flights on the affected routes decreases in the post-HSR period. In particular, at the route-month level in Column (3), the number of treated flights decreases by 19% more than that of control flights in the post-HSR period. The results are also consistent with both the anecdotal evidence[34] and the research findings of Fu et al. (2012).

The results in Table 6 highlight two points related to competition and environment impact. First, the HSR competition directly causes a significant decrease in flight supply. Second, although we do not have the data on air pollution at the route level, we can still infer that the environment benefits associated with the substitution of flights with HSR is

[34] Source: `https://www.bloomberg.com/news/articles/2018-01-09/high-speed-rail-now-rivals-flying-on-key-global-routes`

substantial given the fact that the polluted emissions of airplanes are higher than that of HSR (Janic, 2011).

[Table 6 inserted here]

The results however intensify two concerns that threaten our baseline results. First, the entry of the HSR draws a proportion of travelers away from air travel. A reduction in the number of air travelers could result in an increase in efficiency of check-in process, boarding process, etc., and a consequent decrease in the departure delay, even if no airlines improve their on-time performance. Second, an airline might choose to permanently cancel a flight with poor on-time performance. If this canceled flight suffers from poor on-time performance before the shock, then correlation between competition from HSR and quality improvement could be due to a composition effect.

First, to assess whether the customer churn in airline travel leads to a decrease in the departure delay, we restrict our sample to include observations only around the most important holidays. Specifically, we extract observations seven days before and after the Spring Festival, three days before and after the Mid-autumn day, and three days before and after the National Day[35]. During the travel peak, all modes of transportation, including airplanes, run at full capacity. Thus, the number of travelers taking flights around the holidays should not decrease after the entry of the HSR. If the decrease in the departure delay is due to the entry of the HSR rather than a decrease in the number of air travelers, then we should observe a significantly negative estimate of the treatment dummy in the holiday (subsample) analysis. The significantly negative coefficients of the treatment dummy in Table 7 verify this prediction, indicating that the HSR entry leads to significant reductions in flight delays even when airports and airlines operate at full capacity.

[Table 7 inserted here]

To address the second concern that the on-time performance of canceled flights may be worse than that of continuing flights, we re-estimate equation (3) using flights exist both before and after the HSR entry. Table 8 report the results. In the subsample analysis, the introduction of the HSR is found to be statistically significant in reducing arrival delays, the actual travel time, the excessive travel time, and departure delays, which rules out the possibility that the improvement in the on-time performance of treated flights is caused by the cancellation of flights with poor on-time performance.

[Table 8 inserted here]

[35]In China, the Spring Festival, Mid-Autumn Day, and National Day are considered to be the three most important holidays and cause the biggest transport stress.

6.4 Robustness and Falsification Checks

To address whether our findings are affected by confounding factors and whether the control group were simultaneously affected by the entry of HSR, we conduct a number of robustness checks. First, the estimated treatment effects of HSR could be biased if the local governments or military bases intentionally issue air traffic control on control routes in the post-HSR period. We first use an alternative control group consisting of only international air routes, which are less likely to be affected by the Chinese authorities and are free of HSR shocks. Table 9 reports the results. The coefficients of the interaction term remain significantly negative and the magnitudes are greater than those in the baseline analysis, suggesting that air traffic control on control routes inducing an overestimation is not a concern.

[**Table 9 inserted here**]

Another competing explanation for the improved quality is that the flights in the control group in the post-HSR period experience more delays created by the delays in previous flights. Therefore, the increased delays of flights in the control group in the post-HSR period may also lead to negative estimates of β in the baseline tables. To address this issue, we focus on a subsample that consists only of flights departing in the early morning (6am to 9am) because flights departing in the morning are less likely to be affected by the previous flights. The results in Table 10 show that the estimates of the interaction term are significantly negative in all columns, which are consistent with the baseline results.

[**Table 10 inserted here**]

The third is to check whether airlines, especially hub airlines, reschedule their flights and allocate flights to less congested time slots, which could negatively affect the on-time performance of other non-hub airlines. As shown in Appendix Figure A2, the number of flights increases in all time slots throughout the day after the introduction of the Beijing-Shanghi HSR line[36], implying that airports become busier after the entry of HSR. We then divide a day into 24 hours to identify the peak and off-peak time slots (Appendix Figure A3). The departure flights scheduled for the 1am, 6am, 7am, 9am, 10am and 10–11pm slots have better on-time performance[37]. We then re-estimate equation (3) using a binary variable $Y_{i,j,d,t}$ as the dependent variable. $Y_{i,j,d,t}$ equals to 1 if the flight was scheduled to a better time slot and 0 otherwise. We also calculate the density of flights in the better time slots at the airline-route-month level following equation (5). Results in Table 11 show that the estimated coefficients of $Treatment * After$ are neither positive nor statistically significant, suggesting that the rescheduling hypothesis does not hold.

[36]Appendix Figure A2 plots the average schedule flights at 30-minute intervals on the day before and after the introduction of the Beijing–Shanghai HSR line between January 2009 and December 2012

[37]Figure A3 in the Appendix plots the traffic volume and average departure delay in each time slot before the introduction of the Beijing–Shanghai HSR line. These time slots can thus be considered to be better in terms of departure delays.

[**Table 11 inserted here**]

To test the hypothesis for possible spurious results in either geography or time, we conduct two falsification tests. The first is a placebo test in which we create an artificial treatment group consisting of nine destinations linked to the Beijing–Guangzhou HSR line after December 26, 2012. As discussed above, although these nine cities enter the HSR network after December 26, 2012, none of them was linked to the Beijing–Shanghai HSR line between January 1, 2009 and December 25, 2012. This test addresses whether the difference in the original DID regressions reflects HSR competition or just a more general effect related to the characteristics of HSR destinations.

The second placebo test examines whether the original DID effects simply reflect more general time patterns, either as part of the airline industry cycle or resulting from broader HSR network planning, which affected destinations differently. To do this, we create an artificial treatment date. Specifically, we set the introduction of the Beijing–Shanghai HSR line as occurring one year before when it actually occurred and ensure that both the one-year before and one-year after periods lie in the period before the actual introduction of the Beijing–Shanghai HSR line.

Appendix Tables A7 and A8 report the regression results on the placebo treatment group and placebo treatment date, respectively. In both placebo tests, we find that the estimated coefficients of the interaction terms are not statistically different from zero. This finding concurs with the results above because the difference in the on-time performance in the post-HSR period is caused by the HSR competition not by the characteristics of the HSR destinations or airline industry cycle or broader HSR network planning.

Lastly, we expand the study by focusing on a longer sample period from January 2009 to September 2015 to generalize the finding. The full sample period contains 19 introductions of HSR lines (see Table A1 in the Appendix for more details). In the general study, the number of treated destinations (routes) increased from 11 to 33. Table 12 reports the results of regressing the different measures of on-time performance against the treatment dummy in the expanded sample. The estimated coefficients are consistently negative and statistically significant, supporting the argument that the entry of the HSR spurs airlines to improve their on-time performance.

[**Table 12 inserted here**]

6.5 Heterogeneity Tests

In this section, we explore the heterogeneity in the effects of the HSR on hub and non-hub airlines as well as on short-to-medium-haul and long-haul flights. According to the Civil Aviation Administration, China Air, China Southern Airlines, China Eastern Airlines, Hainan Airlines, and Beijing Capital Airlines are considered to be hub airlines of BCIA.

Hub airlines can absorb greater marginal delay costs than their non-hub peers because they gain network benefits from additional flights (Mayer and Sinai, 2003). Therefore, given that hub and non-hub airlines may have different incentives to improve their quality, they may respond differently to the entry of HSR.

Panel A of Table 13 presents the estimates of the impact of competition from the Beijing–Shanghai HSR line on the on-time performance of hub airline flights compared with that of non-hub airline flights. Hub is a dummy equal to 1 if the flights belong to one of the five hub airlines and 0 otherwise. The estimated coefficients of $Treatment * After * Hub$ are significantly positive for all the measures of on-time performance, indicating that non-hub airlines are more responsive to HSR competition because the treatment effects are larger on non-hub airline flights than that on hub airline flights.

Since HSR lines impose the most fierce competition for air routes within 1,200 km (Fu et al., 2012; Yang and Zhang, 2012), we use 1,200 km[38] as a cutoff to categorize flights into short-to-medium-haul and long-haul routes. Panel B of Table 13 presents the results. STM is a dummy equal to 1 if the distance between Beijing and the destination is below 1,200 km and 0 otherwise. The estimated coefficients of $Treatment * After * STM$ are significantly negative for all four measures of on-time performance, implying that short-to-medium-haul flights are more responsive to competition from HSR lines. Furthermore, Figure 8 plots the coefficients of on-time performance response for the entire distribution of travel distances, ranging from 500 km to over 1,500 km, along with their corresponding 95 percent confidence intervals. Facing competition from HSR, the average quality improvement of short-haul flights is the largest among all other distances.

[Figure 8 inserted here]

[Table 13 inserted here]

7 The Back-of-the-Envelope Calculation on Time Saving

Home to the largest HSR network (60% of the world's total in 2016), China manages HSR lines that cover 24,000 km (15,000 miles). The rapid rate of expansion of the HSR network presents an enormous challenge for Chinese airlines in terms of implementing effective plan-

[38] According to Sachs (2010), the optimal operational efficiency of HSR trains is three to four hours of travel, with efficiency beginning to decrease after four hours. Thus, according to the estimation of Sachs (2010), we can interpret that HSR trains in China are the most competitive for city pairs at a travel distance of 1,200 km given the average speed of 300 kph. Therefore, the launch of the Beijing–Shanghai HSR line serves as an ideal competition shock to the airline routes between Beijing and other cities along the Beijing–Shanghai HSR line given the line's total track length of 1,300 km and total travel time of four to five hours.

ning and formulating response strategies to deal with potential customer churn. Examining the impacts of China's HSR on the non-price characteristics of the airline industry could reveal valuable policy implications for other countries considering or developing an HSR network.

In this section, we use our estimates to conduct a simple back-of-the-envelope calculation of the benefit change due to decreased delays in response to the HSR entry. Following Li et al. (2007), we calculate the flight delay cost (V_i) of an additional hour for a passenger. The formula is given as follows:

$$V_i = \alpha_i * \frac{Wage}{2000}, \quad i \in (1, 2)$$

where $Wage$ denotes the average yearly salary. According to the data released by the National Bureau of Statistics[39], the average yearly salary in Beijing in 2012 was CNY 62,676. The denominator, 2000, represents the total number of efficient working hours in a year[40]. α_i is a parameter that measures the relative time value across passenger types. This is a function of the transport mode choice and purpose of travel. Following Yang and Zhang (2012), we categorize the purpose of travel into two types: business (i=1) and leisure (i=2). According to Li et al. (2007) and Yang and Zhang (2012), the time value of business passengers is set to be three times as large as that of leisure passengers and we set α_1=9 and α_2=3. Therefore, the hourly flight delay costs for business and leisure passengers are CNY 282 and CNY 94, respectively. The estimated willingness to pay for flight delay in our study is less than that in Gayle and Yimga (2018), which report that travelers are willing to pay $1.56 per minute to avoid arrival delays, but is close to the willingness to pay in Prince and Simon (2015), which show that the willingness to pay for a one-hour reduction in travel time is $36 and $15 for business and non-business travelers, respectively.

We next calculate the cost C for all the passengers of an aircraft due to an additional minute of delay:

$$C = \sum_{i=1}^{2} N * \beta * \theta_i * \frac{V_i}{60}, \quad i \in (1, 2)$$

where N denotes the total seat count, β denotes the occupation rate, and θ_i denotes the share of passenger type i. According to the Civil Aviation Administration[41], 46% of all airline passengers travel on business and 54% travel on leisure. That is, θ_1=0.46 and θ_2=0.54. Suppose that each flight has 200 seats on average and an occupancy rate of 80%. Then, the

[39]Source: `http://www.stats.gov.cn/tjsj/sjjd/201305/t20130517_74300.html`.

[40]Suppose people work 8 hours per day, 5 days per week, and 52 weeks per year. After excluding 10 days of statutory public holiday, total efficient working hours are 8*5*52-8*10=2000.

[41]Source: `http://www.mot.gov.cn/tongjishuju/minhang/201806/P020180621341239857728.pdf`.

cost C for all passengers of an aircraft due to an additional minute of delay is 481.28.

Given that our estimated reduction in the arrival delay for all treated flights before September 2015 is 4.36 minutes (as shown in Column 1 of Table 12), a simple estimate of the per flight time saving from the reduced arrival delay in the post-HSR period is equivalent to CNY 4.36*481.28=2,098.38. Notably, this is an lower-band estimation of the total benefits for air travelers on the treated routes because it does not take into account the decrease in airfare caused by the entry of the HSR, or the benefit gained by the travelers switch from airline to HSR. To provide a more intuitive image of the benefits of time saving for air travelers on the affected routes, we use all flights along the HSR routes in the post-HSR period for illustration purposes. In our data, 796,191 treated flights fly from Beijing to the 33 HSR cities between June 30, 2011 and September 30, 2015. The total gain of time saving for air travelers on the affected routes on the round-trip is thus calculated as CNY 796,191*2,098.38*2 =3.34 billion.

8 Discussion and Conclusion

There is no doubt that HSR, one of the major disruptive technologies in transportation, has encroached on air travel, especially on short-to-medium-distance travel. The association of the new high tech product of HSR with speed, punctuality, convenience, safety and comfort, at a time when airlines have been experiencing record delays may encourage passengers to switch to HSR. The specific timing of the entry of HSR lines represents an exogenous shock to the competitive landscape of intercity transportation services. The case that new HSR lines may have an enormous influence on the provision of air services provides an ideal setting to study the causal relationship between competition and quality improvement.

In this study, we use a DID strategy to establish the causal relationship between the entry of HSR and the quality improvement of airlines. Using a method that assumes the placement of HSR stations to be random, existing studies of China's HSR have paid close attention to the economic benefits of HSR, such as GDP, labor mobility, and investment. We differ from the existing literature by providing evidence that airlines respond to the HSR entry in the non-price dimension, an area that has not been studied in the literature or in cost-benefit analysis. The on-time performance of airlines is accurately identified in our dataset, which records real-time flight status, departures and arrivals information of all flights departing from Beijing to various destinations across China. More importantly, we employ the variation in the construction completion dates of HSR stations across cities and conduct a more valid comparison between the 11 treated destinations and nine control destinations, which represents a step towards a cleaner test and allows us to better circumvent the bias issue from non-random treatment.

Our analysis shows that competition from the HSR significantly improves the quality of air transportation services. Specifically, airlines on routes facing competition from HSR lines decreased their arrival delays by an average of 2.5 minutes (15.4%) in the post-HSR period. These effects are persistent and robust to the inclusion of various fixed effects, suggesting that improvements in the operational efficiency of air transportation services are not attributable to changes in airline-level shocks, local market shocks, or adjustments in supply that may have followed the entry of the HSR lines. Decomposing the actual travel time, we find that the decrease in the departure delay and taxi-in runway time are the sources of the improvement in on-time performance. Our results survive both robustness and falsification tests, including the cancellation of flights with poor on-time performance, rescheduling to better time slots, delays of the previous flights, allocating flight from the treatment group to the control group, and air traffic control in the control group. The heterogeneity tests show that non-hub airlines and airlines on routes within 1,200 km are more responsive to HSR competition. Lastly, we provide a back-of-the-envelope analysis and reveal that the total gain for air travelers on the affected round-way flights flying from Beijing to the 33 HSR cities between June 30, 2011 and September 30, 2015 is CNY 3.34 billion.

This study does not estimate the effects of HSR entry on airfares or airline revenues because flight level real-time price data and airline-route level revenue data in China are not publicly available and the negative effect of competition on price has been studied by Goolsbee and Syverson (2008) and Yang and Zhang (2012). A HSR system with current technologies would provide significant environmental benefits over existing travel modes, however, the environmental impact assessment on HSR still lacks of empirical evidence. Our study provides a starting point for assessing the environmental benefits of HSR entry.

Our analyses are intended to provide empirical insights about HSR's status as a disruptive innovation in the transportation industry. Our results have important implications not only for airlines but also for countries assessing the cost and benefits of developing an HSR network. Airlines tend to place responsibility for delays on exogenous factors such as weather conditions and air traffic control, and have not tried their best to minimize delays as they claim to have done. As long as the airline industry face enough competition, the current level of flight delays can be further reduced. Moreover, our results highlight the potential of airlines and airports to further improve the on-time performance and the channels through which competition stimulates quality: minimizing departure delay through more efficient processes of baggage loading/unloading, check-in, and boarding, and reducing runway congestion through better airport surface management and runway scheduling. Our study also sheds light on the cost and benefits of ongoing HSR planning processes. The findings are particularly important given the backdrop of the HSR investment boom in Asia and the huge debate on the construction of HSR systems in the US.

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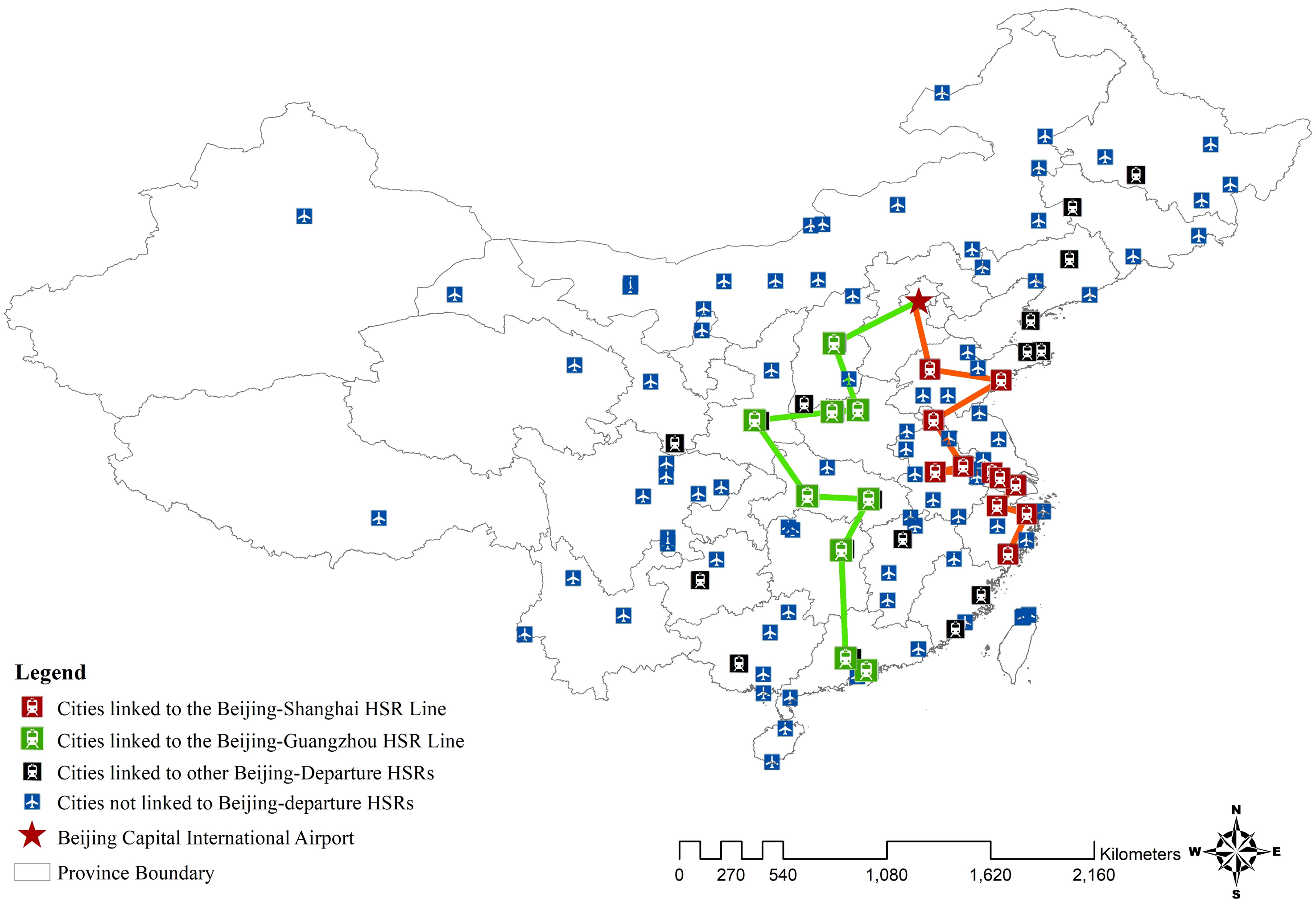
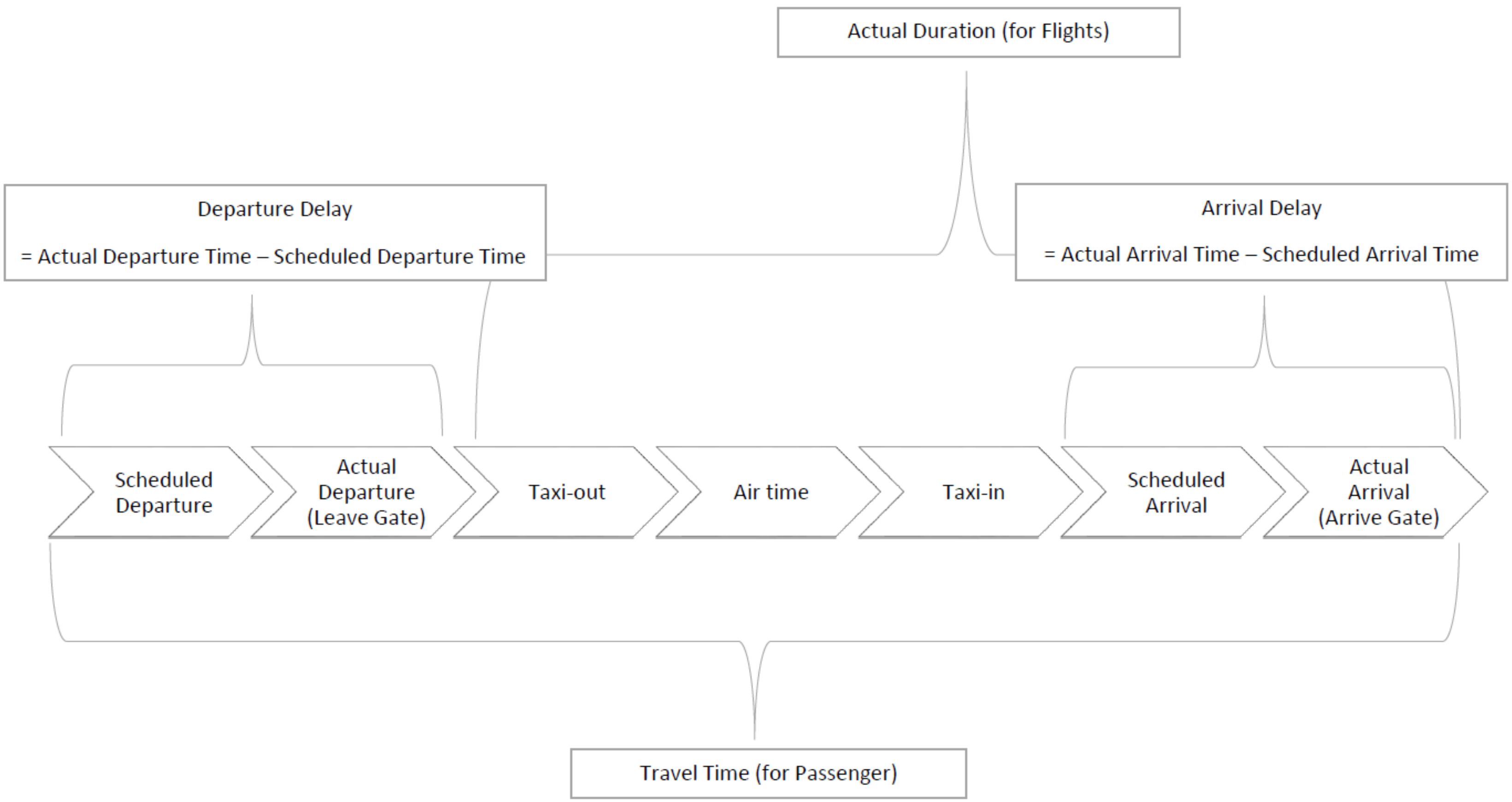
Figure 1: Geographic Distribution of Sample Cities in September 2015



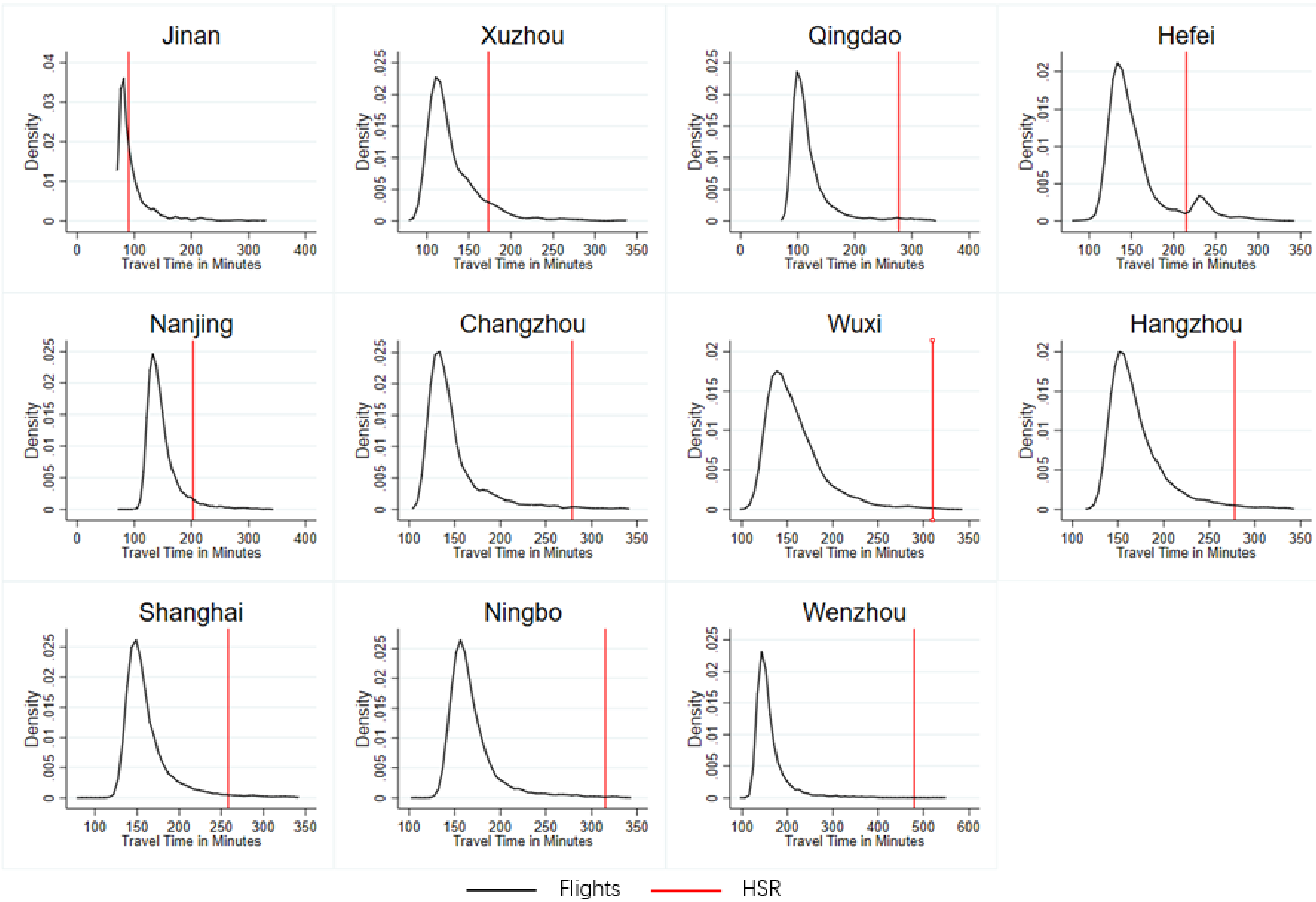
Notes: This figure presents the geographic distribution of the sample destinations in September 2015. The red train signs denote the 11 treated destinations linked to the Beijing–Shanghai HSR line introduced on June 30, 2011. The green train signs denote the nine destinations linked to the Beijing–Guangzhou HSR line introduced on December 26, 2012. The black train signs denote the 13 destinations linked to other Beijing–departure HSR lines, which were introduced after December 26, 2012. The blue airport signs denote the destinations with direct flights from Beijing but not linked to any Beijing-departure HSR lines during our sample period. All the destinations in this figure are linked by direct flights departing from Beijing.

Figure 2: Flowchart for Flight Delays



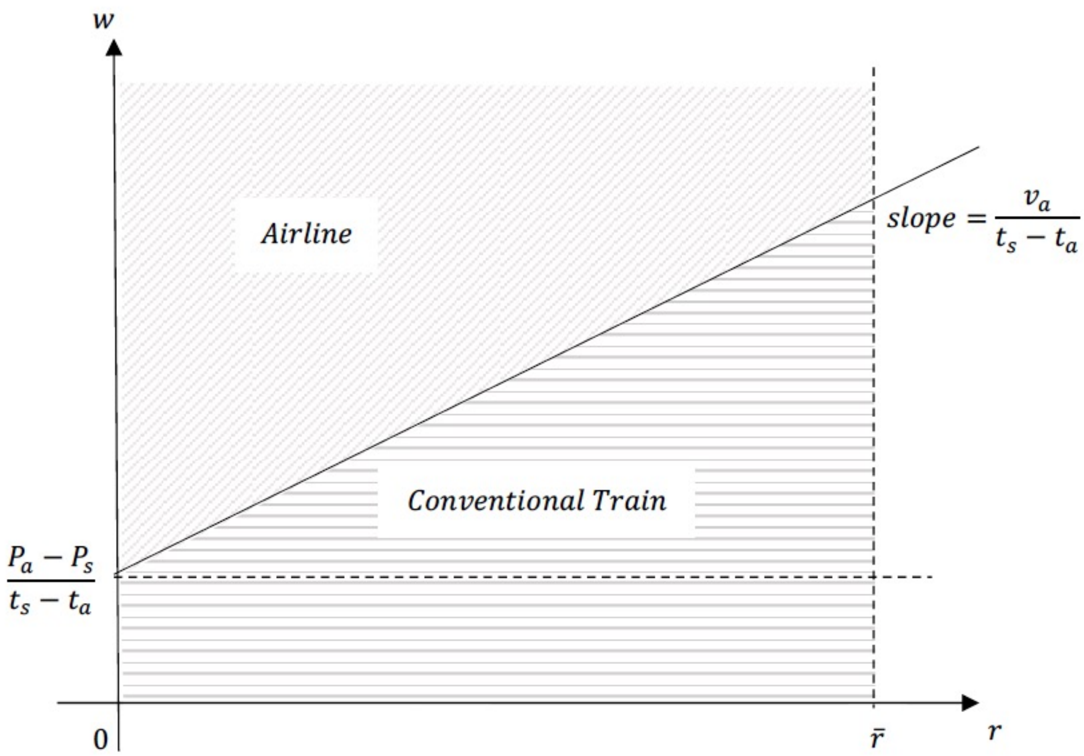
Notes: The flowchart illustrates the components of the flight departure and arrival delays. *Actual Travel Time* (ATT) captures the time difference between the *scheduled departure time* and *actual arrival time.* The *departure delay* is calculated as the time spent before leaving the gate (the difference between the *actual departure time* minus the *scheduled departure time*) and *arrival delay* (the difference between the *actual arrival time* minus the *scheduled arrival time*). The *actual duration* consists of the *taxi-out time* (time spent on the departure runway), airtime, and *taxi-in time* (time spent on the arrival runway).

Figure 3: Distribution of Travel Time for HSRs and Treated Flights



Notes: This figure shows the distributions of travel time (the difference between the actual arrival time minus the scheduled departure time) for the flights linking Beijing and the 11 HSR destinations along the Beijing-Shanghai line (in black), and the distributions of travel time for the corresponding HSR (in red).

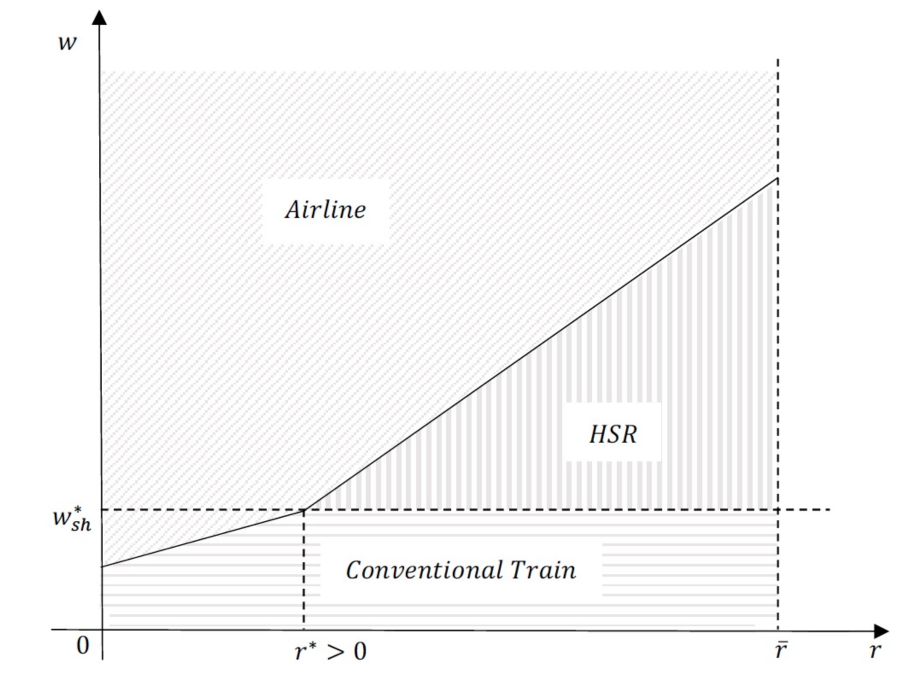
Figure 4: Pre-HSR Transportation Mode Choices



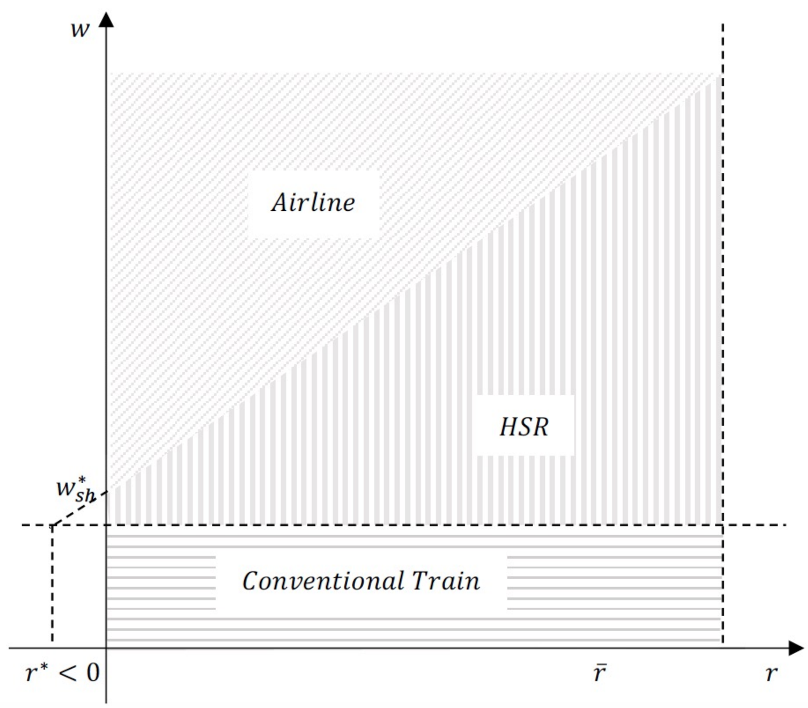
Notes: This figure illustrates the passengers' travel mode choices in the pre-HSR period. The vertical axis represents the unit cost of time, and the horizontal axis represents risk aversion of a passenger. A passenger can choose to travel by air or conventional train. The market shares for air travel and conventional trains are shaded using slanting lines and horizontal lines, respectively.

Figure 5: Post-HSR Transportation Mode Choices

Case 1: r*>0

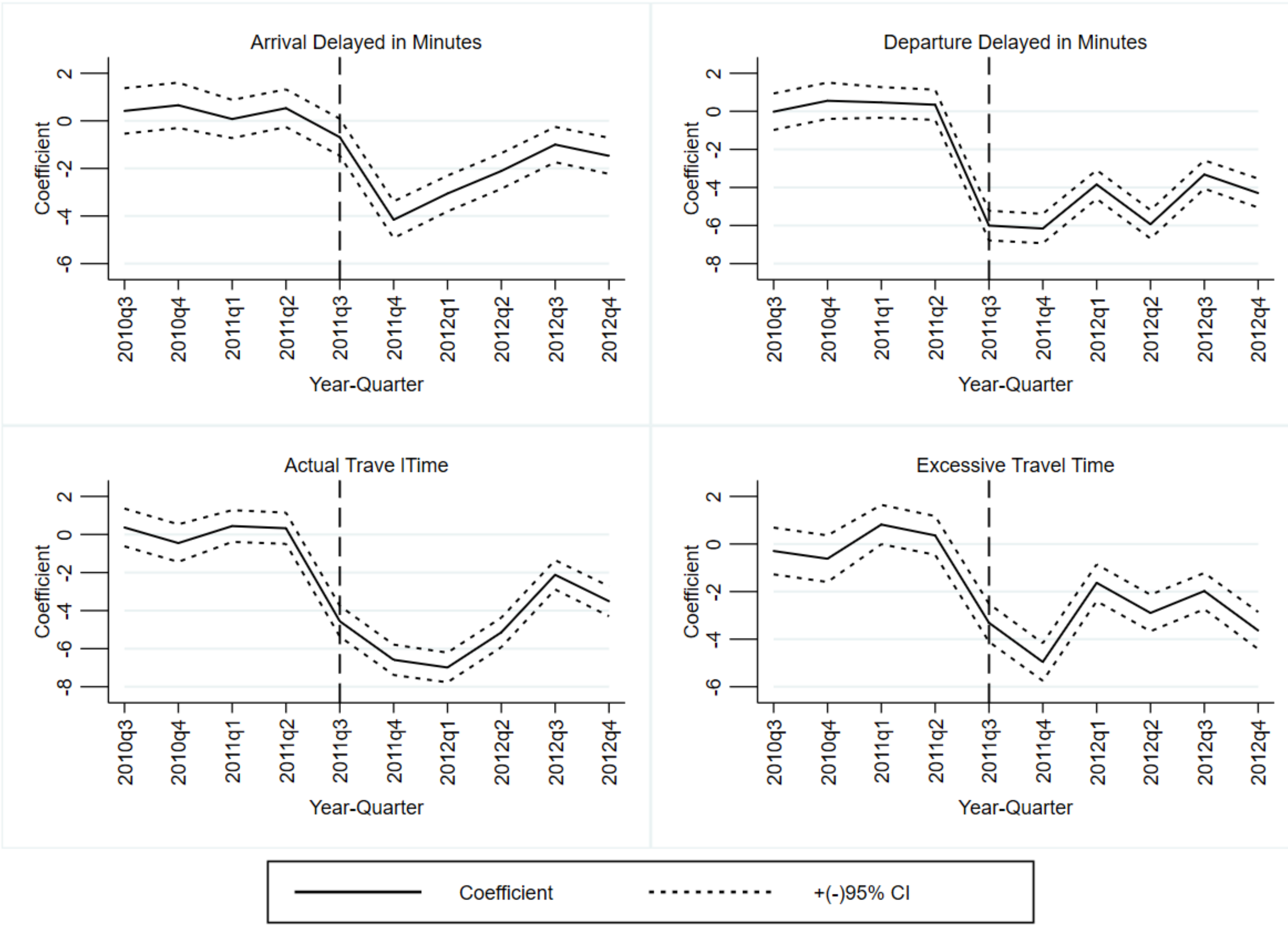


Case 2: r*<0



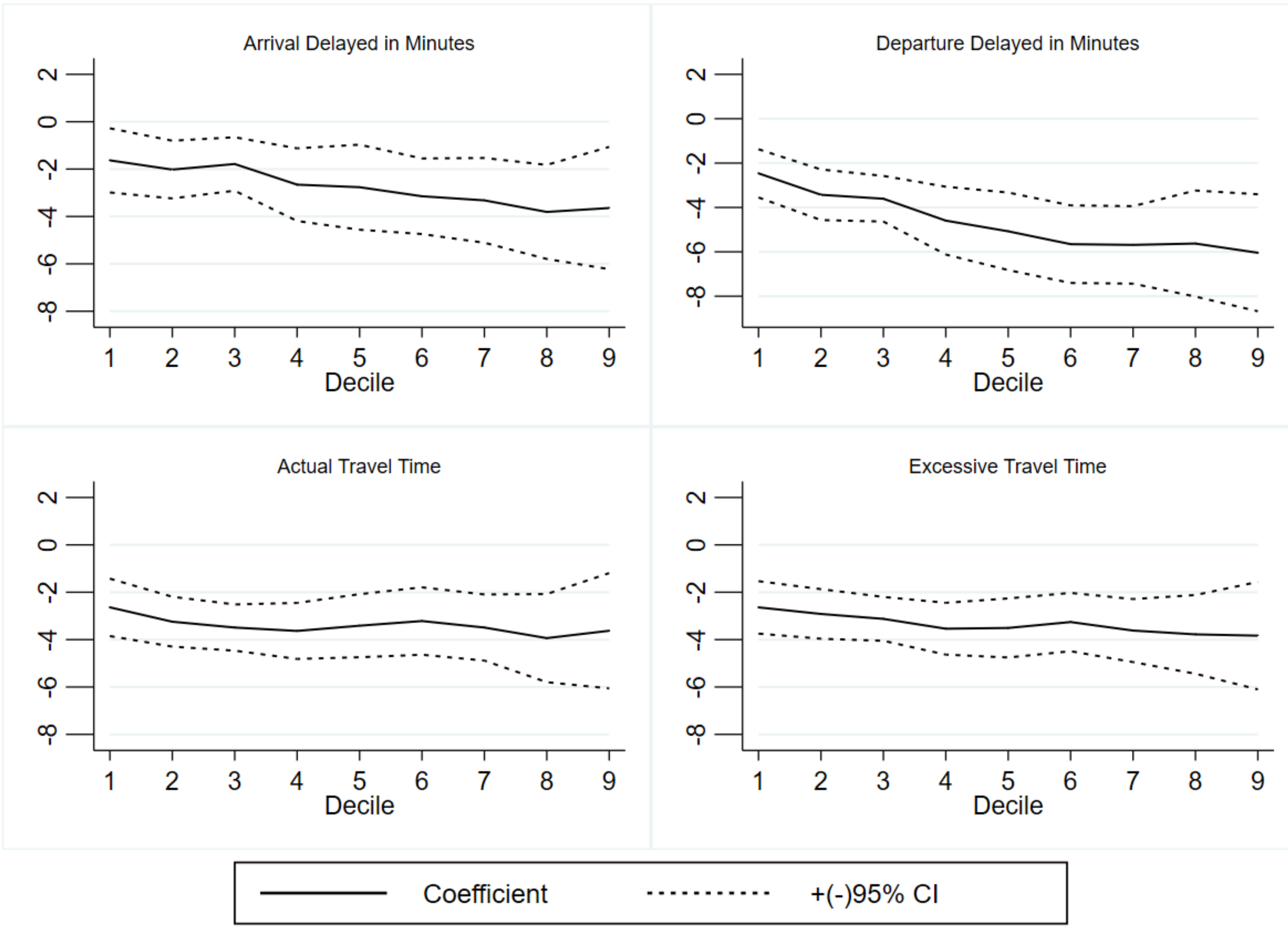
Notes: This figure illustrates the passengers' travel mode choices in the post-HSR period. The market shares for air travel, conventional trains, and HSR are shaded using slanting, horizontal, and vertical lines, respectively.

Figure 6: Dynamic Changes of the Four On-time Performance Measures



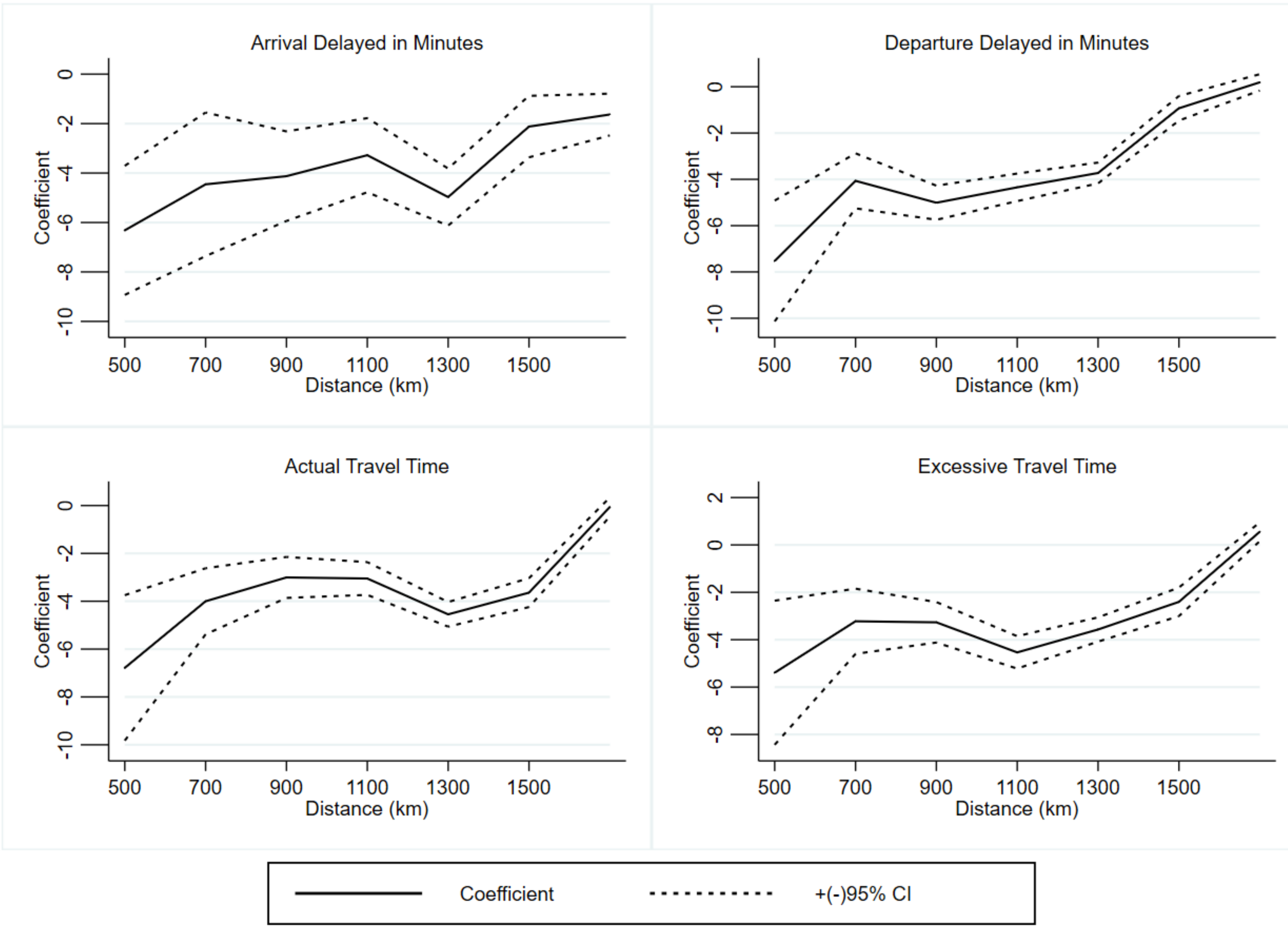
Notes: This figure plots the dynamic responses of the four on-time performance measures to the introduction of the Beijing–Shanghai HSR line. The coefficients are obtained from estimating Equation (4).

Figure 7: Quantile Estimations



Notes: This figure plots the estimates of treatment effect using the quantile regressions (i.e., at quantiles 10% (decile 1), 20% (decile 2), . . . , and 90% (decile 9)). The coefficients are obtained from estimating Equation (3). Standard errors are obtained by bootstrapping using 500 repetitions each time. The dashed lines represent 95% confidence intervals.

Figure 8: Heterogeneity in Distance



Notes:

Table 1: Summary Statistics - Flight Level

	Treatment				Control			
	Before		After		Before		After	
	Mean	S.D	Mean	S.D	Mean	S.D	Mean	S.D
ArrDelay in minutes	17.32	41.91	17.51	35.99	20.42	40.35	22.64	42.99
ArrDelay30	0.16	0.36	0.17	0.37	0.19	0.39	0.22	0.42
DepDelay in minutes	34.73	44.53	36.5	38.26	32.41	41.48	39.37	46.83
DepDelay30	0.35	0.48	0.4	0.49	0.33	0.47	0.41	0.49
Actual Travel Time	129.65	49.09	131.21	43.3	158.17	66.74	166.58	68.51
Excessive Travel Time	32.71	44.44	32.53	38.16	33.09	43.48	36.78	44.79
Actual Duration	94.97	20.1	94.81	19.51	125.68	50.35	127.45	50.33
Schedual Duration	119.45	19.69	123.89	19.92	142.04	48.44	148.93	48.35
Taxi-in Time	15.14	9.73	13.61	9.48	14.37	9.8	14.46	10.21
Taxi-out Time	18.49	13.24	18.11	11.49	19.35	16.2	18.97	15.38
AirTime	62.79	23.9	64.35	23.58	93.19	50.65	94.92	51.02
Observations	98,987		107,266		292,818		366,896	

Notes: This table presents the summary statistics of the treatment and control sample in the baseline analysis. The sample includes all Beijing-departure flights between January 1, 2009 and December 25, 2012. The treatment sample consists of flights departing from Beijing to cities along the Beijing–Shanghai HSR line, and the control sample consists of flights departing from Beijing to other non-HSR cities. The definitions and constructions of the variables are introduced in detail in Section 3.2.

Table 2: Flight level DID - On-time performance Measures

Dep. Variables	ADM	ADD30	DDM	DDD30	ATT	ETT
Model	(1)	(2)	(3)	(4)	(5)	(6)
Treatment*After	-2.539***	-0.025***	-5.282***	-0.034***	-4.726***	-3.919***
	(0.230)	(0.002)	(0.224)	(0.002)	(0. 236)	(1.240)
Observations	865,967	865,967	865,967	865,967	865,967	865,967
R-squared	0.266	0.196	0.254	0.209	0.636	0.208
Hour FE	Yes	Yes	Yes	Yes	Yes	Yes
Date FE	Yes	Yes	Yes	Yes	Yes	Yes
Flight FE	Yes	Yes	Yes	Yes	Yes	Yes

Notes: This table reports the results of estimating Equation (3). We examine the four measures of on-time performance: arrival delay in minutes (ADM), departure delay in minutes (DDM), actual travel time (ATT), and excessive travel time (ETT). ADD30 (DDD30) is a dummy that equals 1 if a flight arrives (departs) at the gate at least 30 minutes late and 0 otherwise. The sample period is from January 1, 2009 to December 25, 2012. The hour, date, and flight fixed effects are included in all specifications. Standard errors clustered by destinations are reported in parentheses. We use ***, **, and * to denote significance at the 1%, 5%, and 10% levels, respectively.

Table 3: Aggregate Level DID - On-time Performance Measures

Dep. Variables	ADM	ADR30	DDM	DDR30	ATT	ETT
	(1)	(2)	(3)	(4)	(5)	(6)
Treatment*After	-3.419**	-0.028***	-5.445***	-0.043**	-5.300***	-4.628***
	(1.441)	(0.011)	(1.723)	(0.021)	(1.217)	(1.195)
Observations	12,499	12,499	12,499	12,499	12,499	12,499
R-squared	0.610	0.640	0.613	0.640	0.958	0.530
Year-Month FE	Yes	Yes	Yes	Yes	Yes	Yes
Airline FE	Yes	Yes	Yes	Yes	Yes	Yes
Route FE	Yes	Yes	Yes	Yes	Yes	Yes

Notes: This table reports the results of estimating the WLS models based on Equation (5), weighting each observation by the number of flights in each cell. We examine the four measures of on-time performance at the airline-route-month level. The ADM, DDM, ATT, ETT denote arrival-delayed in minutes, departure-delayed in minutes, actual travel time, and excessive travel time averaged by airline-route-month, respectively. ADR30 and DDR30 in Columns (2) and (4) represent the proportion of flights arriving and departure at least 30 minutes late, respectively, in the airline-route-month cells. The sample period is from January 1, 2009 to December 25, 2012. The year-month, airline, and route fixed effects are included in all specifications. Standard errors clustered by destinations are reported in parentheses. We use ***, **, and * to denote significance at the 1%, 5%, and 10% levels, respectively.

Table 4: Flight Level DID - On-time Performance Measures (A Cleaner Test)

(Beijing–Shanghai HSR line versus Beijing–Guangzhou HSR line)

Dep. Variables	ADM	ADD30	DDM	DDD30	ATT	ETT
	(1)	(2)	(3)	(4)	(5)	(6)
Treatment*After	-2.241***	-0.035***	-2.991***	-0.030***	-3.587***	-2.345***
	(0.284)	(0.003)	(0.277)	(0.011)	(0.285)	(0.283)
Observations	400,158	400,158	400,158	400,158	400,158	400,158
R-squared	0.296	0.212	0.274	0.213	0.577	0.238
Hour FE	Yes	Yes	Yes	Yes	Yes	Yes
Date FE	Yes	Yes	Yes	Yes	Yes	Yes
Flight FE	Yes	Yes	Yes	Yes	Yes	Yes

Notes: This table reports the results of estimating the HSR competition effects in the subsample. The sample period is from January 1, 2009 to December 25, 2012. The treatment group includes flights departing from Beijing to the 11 destinations linked to the Beijing–Shanghai HSR line. The control group includes flights departing from Beijing to the nine destinations linked to the Beijing–Guangzhou HSR line after December 26, 2012. We examine the four measures of on-time performance: arrival delay in minutes (ADM), departure delay in minutes (DDM), actual travel time (ATT), and excessive travel time (ETT). ADD30 (DDD30) is a dummy that equals 1 if a flight arrives (departs) at the gate at least 30 minutes late and 0 otherwise. The hour, date, and flight fixed effects are included in all specifications. Standard errors clustered by destinations are reported in parentheses. We use ***, **, and * to denote significance at the 1%, 5%, and 10% levels, respectively.

Table 5: Flight Level DID - Sources of Improvement

			Components of Actual Duration			
Dep. Variables	Departure Delay	Actual Duration	Taxi-out	Taxi-in	Air time	Scheduled Duration
Model	(1)	(2)	(3)	(4)	(5)	(6)
Treatment*After	-5.282***	0.391	0.117	-1.389***	1.740***	0.819
	(0. 224)	(0.541)	(0.086)	(0.055)	(0.124)	(0.941)
Observations	865,967	865,967	865,387	865,387	865,387	865,967
R-squared	0.254	0.929	0.097	0.141	0.813	0.976
Hour FE	Yes	Yes	Yes	Yes	Yes	Yes
Date FE	Yes	Yes	Yes	Yes	Yes	Yes
Flight FE	Yes	Yes	Yes	Yes	Yes	Yes

Notes: This table reports the results of estimating the effects of the HSR introduction on the departure delay, actual duration, and scheduled duration. The sample period is from January 1, 2009 to December 25, 2012. The hour, date, and flight fixed effects are included in the individual regressions. The year-month, airline, and route fixed effects are included in the aggregate regressions. Standard errors clustered by destinations are reported in parentheses. We use ***, **, and * to denote significance at the 1%, 5%, and 10% levels, respectively.

Table 6: Flight Level DID - Number of Flights

Dep. Variables	ln(Number of Flights)		
Sample	Flight-Route-Month	Airline-Route-Month	Route-Month
	(1)	(2)	(3)
Treatment*After	-0.088***	-0.135***	-0.192**
	(0.015)	(0.049)	(0.093)
Observations	47,620	15,434	4,751
R-squared	0.557	0.869	0.959
Year-Month FE	Yes	Yes	Yes
Flight FE	Yes	No	No
Airline FE	No	Yes	No
Route FE	No	Yes	Yes

Notes: This table reports the results of estimating the effect of the HSR introduction on flight supply. Supply in Columns (1), (2), and (3) is the number of flights aggregated at the flight-route-month, airline-route-month, and route-month cells, respectively. The year-month fixed effects are included in all specifications. The flight fixed effects are included in Column (1), airline and route fixed effects are included in Column (2), and route fixed effects are included in Column (3). Standard errors clustered by destinations are reported in parentheses. We use ***, **, and * to denote significance at the 1%, 5%, and 10% levels, respectively.

Table 7: Flight Level DID - Holiday Periods

Dep. Variables	ADM	ADD30	DDM	DDD30	ATT	ETT
	(1)	(2)	(3)	(4)	(5)	(6)
Treatment*After	-1.628**	-0.017**	-2.505***	-0.024**	-3.558***	-2.001**
	(0.798)	(0.008)	(0.781)	(0.011)	(0.838)	(0.826)
Observations	54,719	54,719	54,719	54,719	54,719	54,719
R-squared	0.266	0.204	0.239	0.220	0.700	0.202
Hour FE	Yes	Yes	Yes	Yes	Yes	Yes
Date FE	Yes	Yes	Yes	Yes	Yes	Yes
Flight FE	Yes	Yes	Yes	Yes	Yes	Yes

Notes: This table reports the results of estimating Equation (3) on a subsample that includes observations seven days before/after the Spring Festival, three days before/after the Mid-Autumn Day, and three days before/after the National Day. ADM is short for Arrival Delayed in Minutes and DDM is short for Departure Delayed in Minutes. The sample period is from January 1, 2009 to December 25, 2012. The hour, date, and flight fixed effects are included in all specifications. Standard errors clustered by destinations are reported in parentheses. We use ***, **, and * to denote significance at the 1%, 5%, and 10% levels, respectively.

Table 8: DID Tests on Flights Exist both before and after the HSR Entry

Dep. Variables	ADM	ADD30	DDM	DDD30	ATT	ETT
	(1)	(2)	(3)	(4)	(5)	(6)
Treatment*After	-2.579***	-0.026***	-5.374***	-0.035***	-4.717***	-3.975***
	(0.230)	(0.003)	(0.229)	(0.003)	(0.234)	(0.362)
Observations	716,304	716,304	716,304	716,304	716,304	716,304
R-squared	0.262	0.193	0.253	0.206	0.637	0.237
Hour FE	Yes	Yes	Yes	Yes	Yes	Yes
Date FE	Yes	Yes	Yes	Yes	Yes	Yes
Flight FE	Yes	Yes	Yes	Yes	Yes	Yes

Notes: This table includes flights that existed both before and after the introduction of the Beijing–Shanghai HSR line. Panels A and B focus on the estimation results at the individual and the aggregate level, respectively. The hour, date, and flight fixed effects are included in all specifications in Panel A. The year-month, airline, and route fixed effects are included in all specifications in Panel B. Standard errors clustered by destinations are reported in parentheses. We use ***, **, and * to denote significance at the 1%, 5%, and 10% levels, respectively.

Table 9: Flight Level DID - International Flights

Dep. Variables	ADM	ADD30	DDM	DDD30	ATT	ETT
	(1)	(2)	(3)	(4)	(5)	(6)
Treatment*After	-2.215***	-0.026***	-2.141***	-0.036***	-2.606***	-2.684***
	(0.363)	(0.003)	(0.384)	(0.003)	(0.655)	(0.867)
Observations	342,175	342,175	342,175	342,175	342,175	342,175
R-squared	0.290	0.208	0.259	0.277	0.869	0.326
Hour FE	Yes	Yes	Yes	Yes	Yes	Yes
Date FE	Yes	Yes	Yes	Yes	Yes	Yes
Flight FE	Yes	Yes	Yes	Yes	Yes	Yes

Notes: This table reports the results of estimating the effect of the HSR introduction on departure delays with the control group consisting only of international flights. The year-month fixed effects, airline fixed effects, and route fixed effects are included in all specifications. Standard errors clustered by destinations are reported in parentheses. We use ***, **, and * to denote significance at the 1%, 5%, and 10% levels, respectively.

Table 10: Flight Level DID - Morning Flights

Dep. Variables	ADM	ADD30	DDM	DDD30	ATT	ETT
	(1)	(2)	(3)	(4)	(5)	(6)
Treatment*After	-2.057***	-0.019***	-2.717***	-0.023***	-2.992***	-1.993***
	(0.419)	(0.004)	(0.401)	(0.005)	(0.425)	(0.417)
Observations	216,840	216,840	216,840	216,840	216,840	216,840
R-squared	0.318	0.246	0.330	0.257	0.692	0.268
Hour FE	Yes	Yes	Yes	Yes	Yes	Yes
Date FE	Yes	Yes	Yes	Yes	Yes	Yes
Flight FE	Yes	Yes	Yes	Yes	Yes	Yes

Notes: This table focuses on a subsample consisting only of flights departing in the early morning (6am to 9am). The hour, date and flight fixed effects are included all columns. Standard errors clustered by destinations are reported in parentheses. We use ***, **, and * to denote significance at the 1%, 5%, and 10% levels, respectively.

Table 11: DID Tests on the Probability of Schedule Reshuffling

Sample	Flight Level	Aggregate Level
Dep. Variables	Preferred Dummy	Monthly Preferred Rate
	(1)	(2)
Treatment*After	-0.021	-0.020
	(0.019)	(0.021)
Observations	865,967	12,499
R-squared	0.781	0.595
Date FE	Yes	No
Year-Month FE	No	Yes
Flight FE	Yes	No
Airline FE	No	Yes
Route FE	No	Yes

Notes: This table examines whether the affected airlines are more likely to allocate their flights to preferred time zones after the introduction of the HSR. The dependent variable in Column (1) is a dummy equal to 1 if the flight was scheduled in the better time slots and 0 otherwise. The dependent variable in Column (2) is the proportion of flights in the better time slots over the total flights in the airline-route-month cells. The date and flight fixed effects are included in Column (1) and the year-month, airline, and route fixed effects are included in Column (2). Standard errors clustered by destinations are reported in parentheses. We use ***, **, and * to denote significance at the 1%, 5%, and 10% levels, respectively.

Table 12: Flight Level DID - A General Case (January 2009 to September 2015)

Dep. Variables	ADM	ADD30	DDM	DDD30	ATT	ETT
	(1)	(2)	(3)	(4)	(5)	(6)
Treatment*After	-4.357***	-0.024***	-3.553***	-0.039***	-2.455***	-2.154***
	(0.274)	(0.001)	(0.116)	(0.001)	(0.130)	(0.128)
Observations	2,001,362	2,001,362	2,001,362	2,001,362	2,001,362	2,001,362
R-squared	0.231	0.196	0.246	0.220	0.564	0.197
Hour FE	Yes	Yes	Yes	Yes	Yes	Yes
Date FE	Yes	Yes	Yes	Yes	Yes	Yes
Flight FE	Yes	Yes	Yes	Yes	Yes	Yes

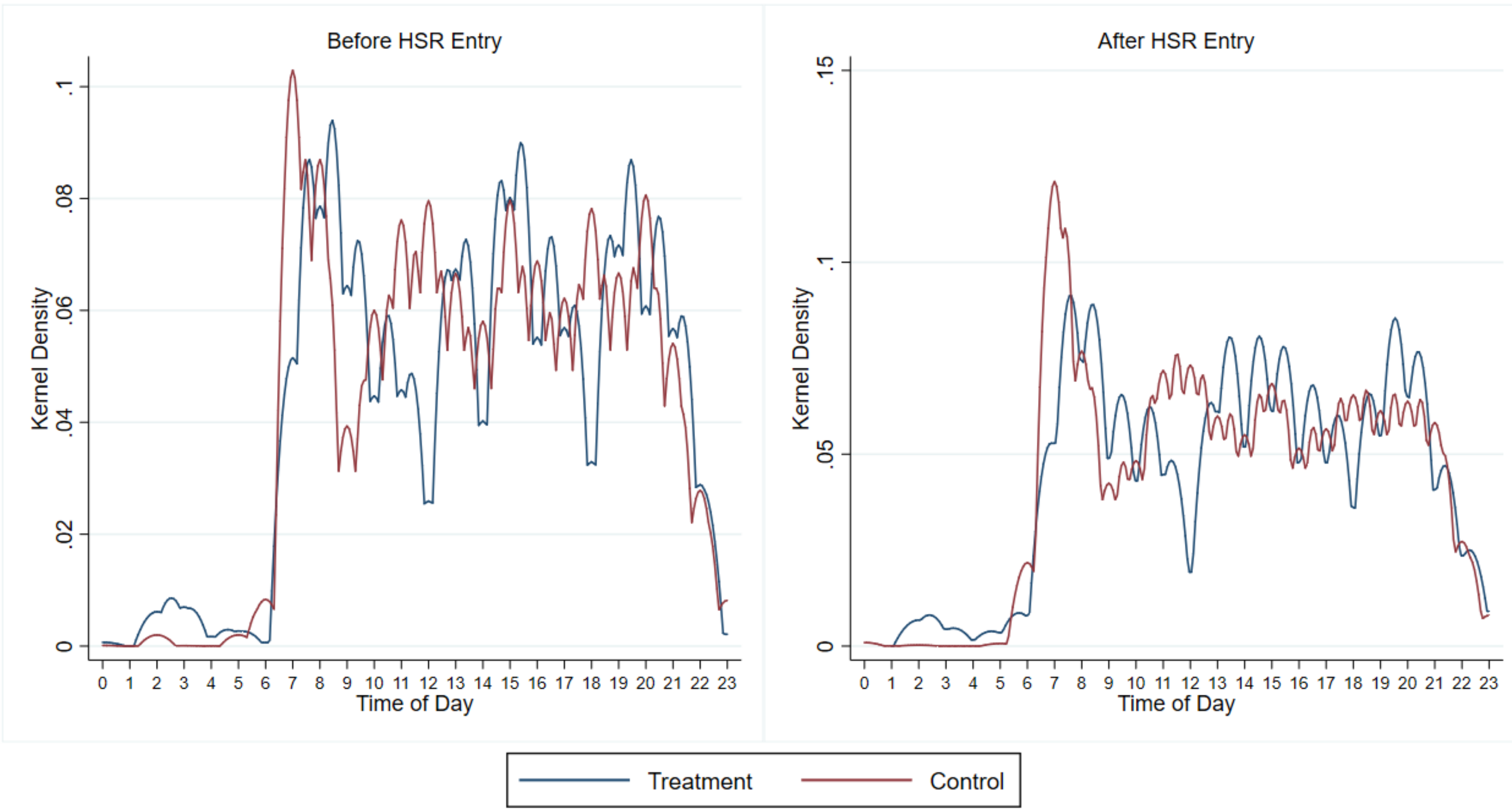
Notes: This table reports the results of estimating the HSR competition effects in an extended sample. The sample period is from January 2009 to September 2015. The number of treated destinations increased from 11 to 33 in September 2015. The estimations are conducted at the airline-route-month level. We examine the four measures of on-time performance: arrival delay in minutes (ADM), departure delay in minutes (DDM), actual travel time (ATT), and excessive travel time (ETT). ADD30 (DDD30) is a dummy that equals 1 if a flight arrives (departs) at the gate at least 30 minutes late and 0 otherwise. The hour, date, and flight fixed effects are included in all specifications. Standard errors clustered by destinations are reported in parentheses. We use ***, **, and * to denote significance at the 1%, 5%, and 10% levels, respectively.

Table 13: Heterogeneity Tests (Individual Level)

	Panel A. Hub Airlines Heterogeneity				Panel B. Distance Heterogeneity			
Dep. Variable	ADM	DDM	ATT	ETT	ADM	DDM	ATT	ETT
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Treatment*After	-6.793***	-3.780***	-3.079***	-1.433***	-2.696**	1.054	-0.889	-0.556
	(0.415)	(0.176)	(0.196)	(0.193)	(1.331)	(0.989)	(0.967)	(0.843)
Treatment*After*Hub	3.698***	0.344*	0.947***	0.422*				
	(0.473)	(0.200)	(0.224)	(0.227)				
Treatment*After*STM					-1.252***	-3.781***	-2.825**	-2.737***
					(0.068)	(0.759)	(1.425)	(0.891)
Observations	2,001,362	2,001,362	2,001,362	2,001,362	2,001,362	2,001,362	2,001,362	2,001,362
R-squared	0.231	0.246	0.564	0.197	0.346	0.517	0.890	0.363
Hour FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Date FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Flight FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

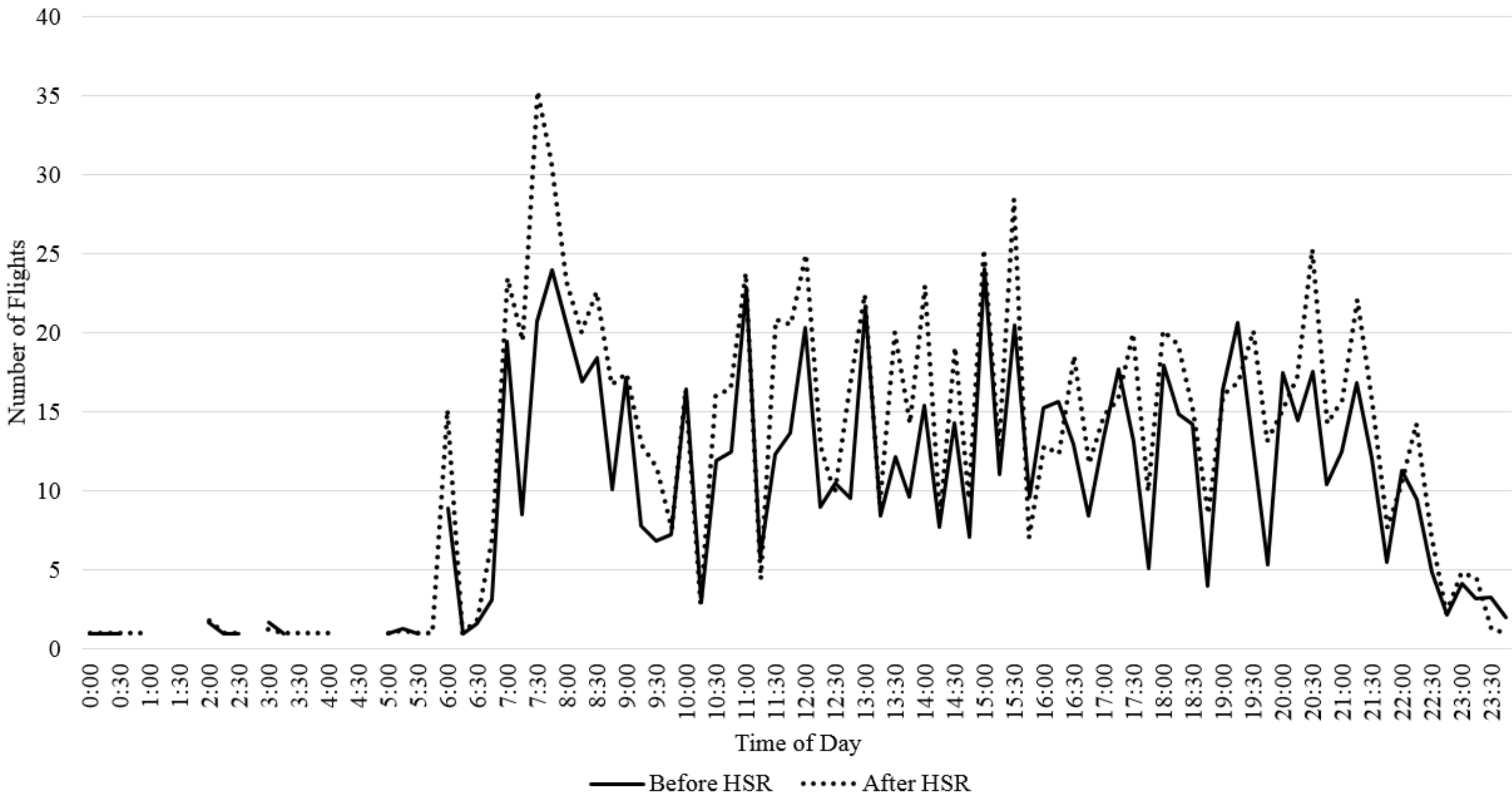
Notes: This table examines the heterogeneity in the HSR competition effects on hub airlines and distance. Hub is a dummy equal to 1 if the flights are under Air China, China South Airlines, China East Airlines, Hainan Airlines, or Beijing Capital Airlines and 0 otherwise. STM is a dummy equal to 1 if the distance between Beijing and the destination is below 1200 km and 0 otherwise. We examine the four measures of on-time performance: arrival delay in minutes (ADM), departure delay in minutes (DDM), actual travel time (ATT), and excessive travel time (ETT). The hour, date, and flight fixed effects are included in all specifications. The estimations are conducted at the individual level. Standard errors clustered by destinations are reported in parentheses. We use ***, **, and * to denote significance at the 1%, 5%, and 10% levels, respectively.

Figure A1: Distribution of Flights throughout the Day



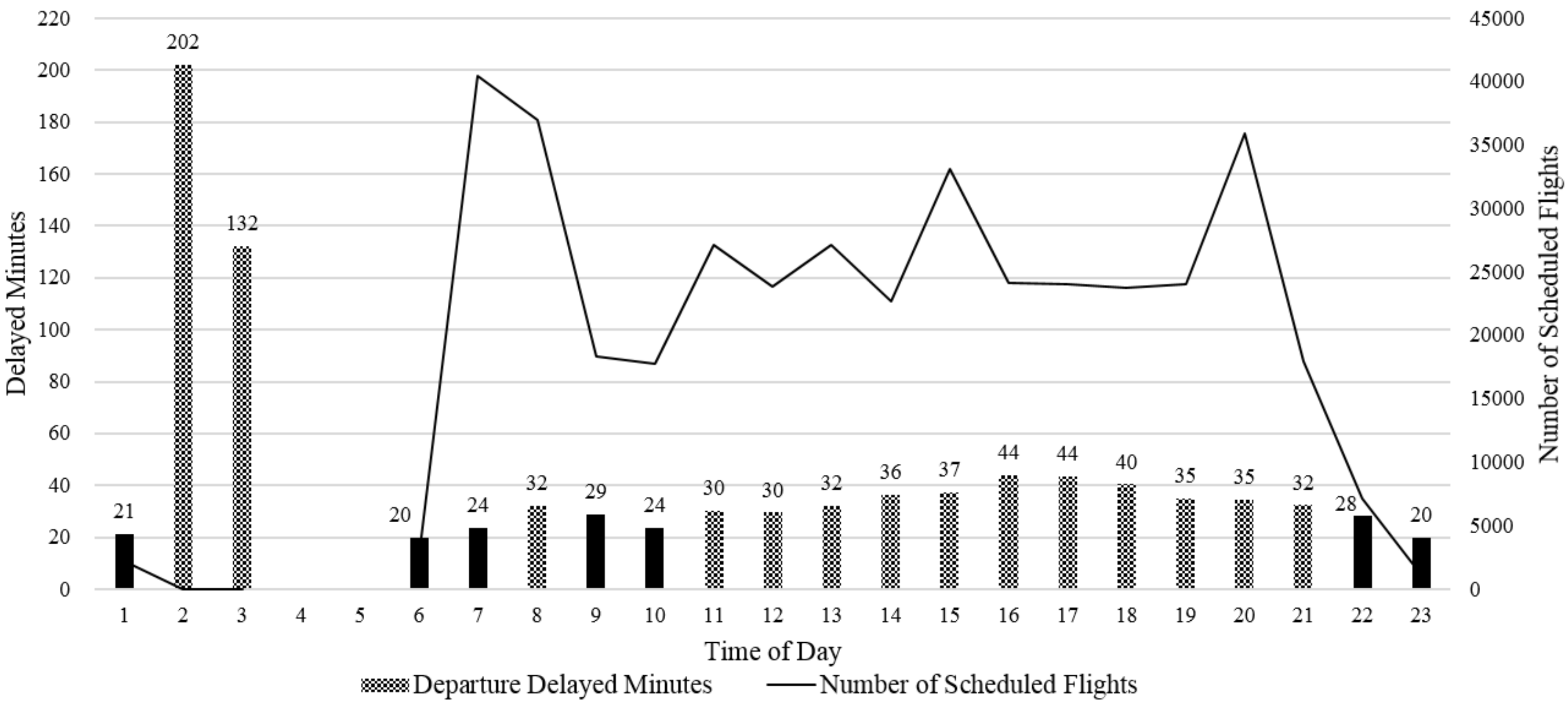
Notes: This figure plots the distribution of flights in the treatment (blue line) and control (red line) groups per hour.

Figure A2: Distributions of the Schedule Time Slots before/after the HSR Entry



Notes: This figure plots the average number of schedule flights at 30-minute intervals on the day before and after the introduction of the Beijing–Shanghai HSR line between January 2009 and December 2012. The solid line represents the distribution of scheduled flights before the introduction of the Beijing–Shanghai HSR line and the dotted line represents the distribution of scheduled flights after the introduction of the Beijing–Shanghai HSR line.

Figure A3: Distribution of the Departure Delay throughout the Day



Notes: This figure plots the traffic volume and average departure delay in each time slot before the introduction of the Beijing–Shanghai HSR line. The solid line represents the average departure delay per hour. The bar represents the number of flights by hour, with the solid bar denoting the preferred time slots.

Table A1: HSR cities Linked to Beijing

City	Province	Travel Time	Distance	Opening Date	HSR Line
Tianjin	Tianjin	41minute	120km	2008-8-1	Beijing-Tianjin
Langfang	Hebei	22minute	60km	2011-6-30	Beijing-Shanghai
Cangzhou	Hebei	52minute	210km	2011-6-30	Beijing-Shanghai
Dezhou	Shandong	1hour13minute	314km	2011-6-30	Beijing-Shanghai
Jinan	Shandong	1hour56minute	406km	2011-6-30	Beijing-Shanghai
Tai'an	Shandong	2hour16minute	465km	2011-6-30	Beijing-Shanghai
Jining	Shandong	2hour46minute	550km	2011-6-30	Beijing-Shanghai
Zaozhuang	Shandong	3hour3minute	627km	2011-6-30	Beijing-Shanghai
Xuzhou	Jiangsu	3hour17minute	692km	2011-6-30	Beijing-Shanghai
Suzhou	Anhui	3hour29minute	760km	2011-6-30	Beijing-Shanghai
Qingdao	Shandong	4hour38minute	819km	2011-6-30	Beijing-Shanghai
Bengbu	Anhui	3hour37minute	848km	2011-6-30	Beijing-Shanghai
Chuzhou	Anhui	4hour14minute	964km	2011-6-30	Beijing-Shanghai
Hefei	Anhui	3hour55minute	1000km	2011-6-30	Beijing-Shanghai
Nanjing	Jiangsu	4hour35minute	1023km	2011-6-30	Beijing-Shanghai
Zhenjiang	Jiangsu	4hour55minute	1053km	2011-6-30	Beijing-Shanghai
Liu'an	Anhui	5hour24minute	1072km	2011-6-30	Beijing-Shanghai
Changzhou	Jiangsu	5hour8minute	1153km	2011-6-30	Beijing-Shanghai
Wuxi	Jiangsu	5hour25minute	1210km	2011-6-30	Beijing-Shanghai
Suzhou	Jiangsu	5hour33minute	1237km	2011-6-30	Beijing-Shanghai
Kunshan	Jiangsu	5hour30minute	1268km	2011-6-30	Beijing-Shanghai
Hangzhou	Zhejiang	5hour52minute	1279km	2011-6-30	Beijing-Shanghai
Shanghai	Shanghai	5hour6minute	1318km	2011-6-30	Beijing-Shanghai
Shaoxing	Zhejiang	5hour15minute	1322km	2011-6-30	Beijing-Shanghai
Ningbo	Zhejiang	7hour0minute	1434km	2011-6-30	Beijing-Shanghai
Quzhou	Zhejiang	7hour38minute	1548km	2011-6-30	Beijing-Shanghai
Wenzhou	Zhejiang	9hour41minute	1673km	2011-6-30	Beijing-Shanghai
Shijiazhuang	Hebei	1hour19minute	281km	2012-12-26	Beijing-Guangzhou (Beijing-Zhengzhou Section)
Handan	Hebei	2hour14minute	456km	2012-12-26	Beijing-Guangzhou (Beijing-Zhengzhou Section)
Taiyuan	Shanxi	2hour43minute	513km	2012-12-26	Beijing-Guangzhou (Beijing-Zhengzhou Section)
Anyang	Henan	2hour40minute	516km	2012-12-26	Beijing-Guangzhou (Beijing-Zhengzhou Section)
Zhengzhou	Henan	3hour25minute	693km	2012-12-26	Beijing-Guangzhou (Beijing-Zhengzhou Section)
Luoyang	Henan	5hour17minute	832km	2012-12-26	Beijing-Guangzhou (Beijing-Zhengzhou Section)

Table A1 Continues

Xian	Sanxi	5hour51minute	1212km	2012-12-26	Beijing-Guangzhou (Beijing-Zhengzhou Section)
Wuhan	Hubei	5hour40minute	1229km	2012-12-26	Beijing-Guangzhou (Beijing-Zhengzhou Section)
Huanggang	Hubei	5hour47minute	1294km	2012-12-26	Beijing-Guangzhou (Beijing-Zhengzhou Section)
Yichang	Hubei	6hour18minute	1525km	2012-12-26	Beijing-Guangzhou (Beijing-Zhengzhou Section)
Changsha	Hunan	5hour42minute	1631km	2012-12-26	Beijing-Guangzhou (Beijing-Zhengzhou Section)
Guangzhou	Guangdong	9hour21minute	2298km	2012-12-26	Beijing-Guangzhou (Beijing-Zhengzhou Section)
Shenzhen	Guangdong	10hour36minute	2409km	2012-12-26	Beijing-Guangzhou (Beijing-Zhengzhou Section)
Tangshan	Hebei	1hour29minute	241km	2013-12-31	Tianjin-Qinhuangdao
Qinhuangdao	Hebei	2hour1minute	388km	2013-12-31	Tianjin-Qinhuangdao
Shenyang	Liaoning	3hour58minute	786km	2013-12-31	Tianjin-Qinhuangdao
Dalian	Liaoning	4hour52minute	963km	2013-12-31	Tianjin-Qinhuangdao
Changchun	Jilin	6hour19minute	1103km	2013-12-31	Tianjin-Qinhuangdao
Jilin	Jilin	5hour57minute	1214km	2013-12-31	Tianjin-Qinhuangdao
Harbin	Heilongjiang	7hour16minute	1331km	2013-12-31	Tianjin-Qinhuangdao
Baoji	Sanxi	7hour16minute	1379km	2013-12-31	Xuzhou-Lanzhou (Xi'an-Baoji Section)
Fuzhou	Fujian	9hour14minute	1808km	2013-7-1	Hangzhou-Shenzhen (Hangzhou-Ningbo Section)
Quanzhou	Fujian	10hour55minute	1963km	2013-7-1	Hangzhou-Shenzhen (Hangzhou-Ningbo Section)
Yantai	Shandong	7hour16minute	961km	2014-12-28	Qingdao-Rongcheng (Jimo-Rongcheng Section)
Weihai	Shandong	7hour20minute	1063km	2014-12-28	Qingdao-Rongcheng (Jimo-Rongcheng Section)
Yuncheng	Shanxi	6hour12minute	922km	2014-7-1	Datong-Xi'an (Taiyuan-Xi'an Section)
Xiamen	Fujian	10hour55minute	2053km	2014-7-1	Hangzhou-Shenzhen (Hangzhou-Ningbo Section)
Nanchang	Jiangxi	9hour4minute	1933km	2014-9-16	Shanghai-Kunming (Nanchang-Changsha Section)
Nanning	Guangxi	13hour58minute	2478km	2014-9-25	Liuzhou-Nanning
Chongqing	Chongqing	12hour11minute	2078km	2015-1-1	Chongqing-Wuhan
Anqing	Anhui	7hour4minute	1257km	2015-12-6	Ningbo-Anqing
Huangshan	Anhui	6hour29minute	1306km	2015-7-1	Hefei-Fuzhou
Guiyang	Guizhou	10hour47minute	2297km	2015-7-1	Shanghai-Kunming (Xinhuang-Guiyang Section)

Notes: This table summarizes the HSR destinations linked to Beijing along the different HSR lines before September 2015. It also reports the province to which an HSR city belongs, the travel time, the proximity to Beijing in kilometers, the HSR entry date, and the official name of the HSR line.

Table A2: Summary Statistics - Aggregate Level (airline-route-month)

	Treatment				Control			
	Before		After		Before		After	
	Mean	S.D	Mean	S.D	Mean	S.D	Mean	S.D
ArrDelay in minutes	18.31	15.46	17.08	13.43	20.57	16.93	20.99	15.27
ArrDelay30	0.08	0.1	0.13	0.12	0.1	0.12	0.17	0.14
DepDelay in minutes	34.31	16.46	36.16	14.07	31.83	17.51	38.03	18.49
DepDelay30	0.18	0.18	0.33	0.19	0.18	0.18	0.35	0.2
Travel Time	129.05	26.62	128.84	24.92	154.34	51.39	160.63	52.48
Excessive Travel Time	31.78	14.48	31.77	12.96	31.66	16.91	34.69	15.18
Actual Duration	102.36	22.1	99.12	21.06	128.62	48.35	126.64	48.41
Schedual Duration	114.22	22.32	119.91	21.61	137.1	47.73	144.62	48.39
Taxi-in Time	14.93	2.19	14.19	3.47	14.86	2.86	14.93	4.6
Taxi-out Time	18.38	4.73	18.24	4.72	19.71	6.61	19.18	6.25
AirTime	63.81	19.4	65.59	20.09	90.47	45.61	92.55	46.76
Observations	1,164		1,132		4,965		5,238	

Notes: This table presents the airline-route-month level summary statistics of the treatment and control sample in the baseline analysis. The sample includes all Beijing-departure flights between January 1, 2009 and December 25, 2012. The definitions and constructions of the variables are introduced in detail in Section 3.2.

Table A3: Comparison of the Treatment and Control Groups before the Introduction of the Beijing–Shanghai HSR Line

	Treatment		Control1		Control2		Treatment-Control1	Treatment-Control2
	Mean	S.D	Mean	S.D	Mean	S.D	Diff. in Mean 1	Diff. in Mean 2
Population	711.37	276.54	512.45	420.06	633.84	228.45	198.92***	77.53
Income	44,954.40	10,423.92	33,647.11	7,562.63	38,749.80	10,298.26	11,307.29***	6,204.60
GDP	5,525.21	4,011.51	2,076.58	2,100.36	4,889.10	3,304.22	3,448.63**	636.11
Number of Flights	5,994.15	8,474.74	1,906.10	2,898.06	5,838.41	4,656.27	4,088.05***	155.74
DepDelay in minutes	32.90	8.30	35.25	11.63	33.94	8.40	-2.35**	-1.04
ArrDelay in minutes	16.92	11.55	19.30	15.40	18.19	10.49	-2.38***	-1.27*
Travel Time	123.29	25.67	146.85	48.59	144.54	44.54	-23.56***	-21.25**
Excessive Travel Time	32.37	6.82	33.41	10.35	33.47	5.67	-1.04	-1.10

Notes: *Treatment* refers to flights departing from Beijing to 11 destinations linked to the Beijing–Shanghai HSR line. *Control*1 refers flights departing from Beijing to 102 destinations not linked to the Beijing–Shanghai HSR line. *Control*2 refers to flights departing from Beijing to nine destinations linked to the Beijing–Guangzhou HSR line.

Appendix Table A4: Tests on the Common Trend Assumption

Dep. Variables	ADM	ADD30	DDM	DDD30	ATT	ETT
Model	(1)	(2)	(3)	(4)	(5)	(6)
Treatment*Before	-0.874	-0.013	-0.221	0.009	-1.336	-0.012
	(1.230)	(0.022)	(0.363)	(0.009)	(1.376)	(0.372)
Treatment*After	-3.257***	-0.036***	-5.515***	-0.027***	-6.642***	-3.929***
	(0.378)	(0.004)	(0.375)	(0.004)	(0.388)	(0.385)
Observations	865,967	865,967	865,967	865,967	865,967	865,967
R-squared	0.266	0.196	0.259	0.210	0.636	0.208
Hour FE	Yes	Yes	Yes	Yes	Yes	Yes
Date FE	Yes	Yes	Yes	Yes	Yes	Yes
Flight FE	Yes	Yes	Yes	Yes	Yes	Yes

Notes: This table examines the common trend assumption in the DID analysis. The sample period is from January 1, 2009 to December 25, 2012. *Before* is a binary variable equal to 1 for the 18 months (2010:01–2011:06) before the introduction of the Beijing–Shanghai HSR line and 0 otherwise. The estimations are conducted at the individual level. The hour, date, and flight fixed effects are included in all specifications. Standard errors clustered by destinations are reported in parentheses. We use ***, **, and * to denote significance at the 1%, 5%, and 10% levels, respectively.

Table A5: Flight Level DID - Arrival Delays with Route and Airline Level shocks

	Panel A: With Route Shocks		Panel B: With Airline Shocks	
Dep. Variables	ADM	ADD30	ADM	ADD30
Model	(1)	(2)	(3)	(4)
Treatment*After	-3.413***	-0.031***	-1.947***	-0.025***
	(0.243)	(0.002)	(0.241)	(0.002)
Observations	865,967	865,967	865,967	865,967
R-squared	0.274	0.203	0.272	0.200
Hour FE	Yes	Yes	Yes	Yes
Date FE	Yes	Yes	Yes	Yes
Flight FE	Yes	Yes	Yes	Yes
Route-Year-Month FE	Yes	Yes	No	No
Airline-Year-Month FE	No	No	Yes	Yes

Notes: This table reports the results of estimating Equation (3). ADM is short for Arrival Delayed in Minutes. ADD30 is a dummy that equals 1 if a flight arrives at the gate at least 30 minutes late and 0 otherwise. The sample period is from January 1, 2009 to December 25, 2012. The hour, date, and flight fixed effects are included in all specifications. The route dummy interacted with the year-month dummy is included in Columns 1 and 2, and the airline dummy interacted with the year-month dummy is included in Columns 3 and 4. Standard errors clustered by destinations are reported in parentheses. We use ***, **, and * to denote significance at the 1%, 5%, and 10% levels, respectively.

Table A6. Beijing–Shanghai HSR Line versus Beijing–Guangzhou HSR Line (Shenzhen, Guangzhou and Shanghai excluded)

Dep. Variables	ADM	ADD30	DDM	DDD30	ATT	ETT
	(1)	(3)	(6)	(8)	(4)	(5)
Treatment*After	-3.703***	-0.026***	-3.474***	-0.023***	-4.254***	-2.723***
	(0.365)	(0.003)	(0.357)	(0.004)	(0.364)	(0.362)
Observations	237,401	237,401	237,401	237,401	237,401	237,401
R-squared	0.288	0.206	0.285	0.222	0.431	0.237
Hour FE	Yes	Yes	Yes	Yes	Yes	Yes
Date FE	Yes	Yes	Yes	Yes	Yes	Yes
Flight FE	Yes	Yes	Yes	Yes	Yes	Yes

Notes: This table reports the results of repeating regressions in Table 4, with Shenzhen, Guangzhou and Shanghai excluded. The sample period is from January 1, 2009 to December 25, 2012. The treatment group includes flights departing from Beijing to the 10 intermediate destinations linked to the Beijing–Shanghai HSR line. The control group includes flights departing from Beijing to the seven intermediate destinations linked to the Beijing–Guangzhou HSR line. The estimations are conducted at the individual level. We examine the four measures of on-time performance: arrival delay in minutes (ADM), departure delay in minutes (DDM), actual travel time (ATT), and excessive travel time (ETT). ADD30 (DDD30) is a dummy that equals 1 if a flight arrives (departs) at the gate at least 30 minutes late and 0 otherwise. The hour, date, and flight fixed effects are included in all specifications. Standard errors clustered by destinations are reported in parentheses. We use ***, **, and * to denote significance at the 1%, 5%, and 10% levels, respectively.

Table A7: Falsification Tests - Placebo Treatment Group

Dep. Variables	ADD	ADR30	DDM	DDR30	ATT	ETT
	(1)	(2)	(3)	(4)	(5)	(6)
Treatment*After	0.416	-0.006	-2.102	0.001	0.046	-0.593
	(1.619)	(0.013)	(1.320)	(0.016)	(1.219)	(1.048)
Observations	10,203	10,203	10,203	10,203	10,203	10,203
R-squared	0.509	0.553	0.529	0.652	0.936	0.382
Year-Month FE	Yes	Yes	Yes	Yes	Yes	Yes
Airline FE	Yes	Yes	Yes	Yes	Yes	Yes
Route FE	Yes	Yes	Yes	Yes	Yes	Yes

Notes: This table reports the results of a placebo test by creating an artificial treatment group consisting of nine destinations linked to the Beijing–Guangzhou HSR line after December 26, 2012. The destinations in the artificial treatment group were not linked to the Beijing–Shanghai HSR line between January 1, 2009 and December 25, 2012. In this regression, the 11 real treated destinations linked to the Beijing–Shanghai HSR line are excluded. The year-month, airline, and route fixed effects are included in the aggregate level analysis. Standard errors clustered by destinations are reported in parentheses. We use ***, **, and * to denote significance at the 1%, 5%, and 10% levels, respectively.

Table A8: Falsification Tests - Placebo Treatment Date

Dep. Variables	ADD	ADR30	DDM	DDR30	ATT	ETT
	(1)	(2)	(3)	(4)	(5)	(6)
Treatment*After	2.366	0.008	1.011	0.017	1.420	0.086
	(1.985)	(0.009)	(1.752)	(0.017)	(1.587)	(1.145)
Observations	6,129	6,129	6,158	6,129	6,129	6,129
R-squared	0.498	0.606	0.540	0.655	0.921	0.384
Year-Month FE	Yes	Yes	Yes	Yes	Yes	Yes
Airline FE	Yes	Yes	Yes	Yes	Yes	Yes
Route FE	Yes	Yes	Yes	Yes	Yes	Yes

Notes: This table tests an artificial treatment date, which is placed at a point (e.g., on June 30, 2010) one year before the introduction (e.g., on June 30, 2011) of the Beijing–Shanghai HSR line. The year-month, airline, and route fixed effects are included in the aggregate level analysis. Standard errors clustered by destinations are reported in parentheses. We use ***, **, and * to denote significance at the 1%, 5%, and 10% levels, respectively.

Online Appendix: Relationship between HSR Competition and Flight Delays

This section complements the empirical analysis by assessing the correlation between flight delays and the number of scheduled HSR on a route.

To identify the competition effect in the railway industry, we examine whether flight delays correlate with the number of trains, either HSR or conventional train, on a route. We manually collect the railway schedules for trains departing from Beijing to all destinations on six random days: April 1, 2009, December 16, 2010, July 10, 2011, January 1, 2012, June 6, 2012, and May 1, 2013. As railway schedules do not change frequently (at least not on a monthly basis), we use the railway schedules on these six days to represent the schedules in the respective month. We then compute the number of trains by route (from Beijing to a destination) per day. The scheduled HSR frequency on April 1, 2009 and December 16, 2010 is 0 because the first Beijing-departure HSR line was introduced on June 30, 2011.

Figure OA1 presents the unconditional correlations of flight delays with the scheduled HSR frequencies in four months: July 2011, January 2012, June 2012, and May 2013. The y-axes indicate the two measures of delays (*delayed minutes* and *delayed rate*) for arrival flights (top two graphs) and departure flights (bottom two graphs) at the month level[42] and the x-axes denote the number of scheduled HSR trains per day in a month. The negative relationships shown in all four graphs in Figure OA1 indicate that the larger the number of scheduled HSR trains on a route, the lower is the number of minutes a flight on the route is delayed, suggesting that competition from HSR prompts airlines to improve their operational efficiency.

To control for other unobservable effects, we measure the conditional correlation between scheduled HSR frequency and flight delays by capturing an extensive set of fixed effects, including indicators for hour, day, and flight. Table OA1 reports the estimates from the regression models. Specifically, we examine whether a flight faces any competition from HSR trains in Columns (1) and (2) and whether a flight faces any competition from conventional trains in Columns (3) and (4). Each observation represents a particular flight in April 2009, December 2010, July 2011, January 2012, June 2012, and May 2013. The observations in the first two columns are fewer than those in the last two columns because Columns (1) and (2) only include flights on the HSR lines in July 2011, January 2012, June 2012, and May 2013, while Columns (3) and (4) include flights on all non-HSR lines in April 2009, December 2010, July 2011, January 2012, June 2012, and May 2013. The coefficients of the number of HSR trains are negative and significant in Columns (1) and (2), supporting the competition argument in Figure OA1. Specifically, a one-unit increase in the number

[42] The *delayed minutes* measure represents the average number of minutes late all flights arrive (or depart) on a route in a month relative to their scheduled arrival (or departure) time. The *delayed rate* refers to the proportion of flights that arrive (or depart) at least 15 minutes late on a route in a month.

Table OA1: Relationship between number of trains and flight delay

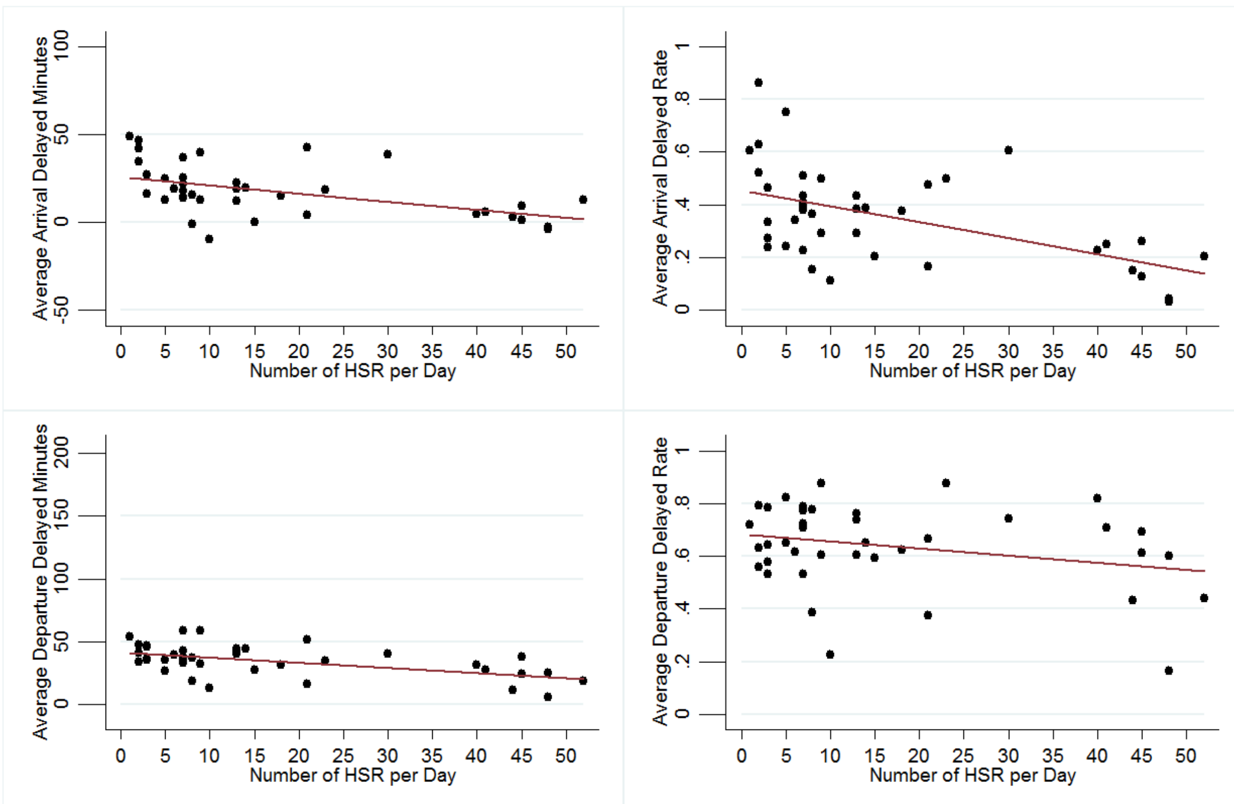
Dep. Variables	HSRs		Conventional Trains	
	ADM	DDM	ADM	DDM
	(1)	(2)	(3)	(4)
Number of Trains	-0.791**	-0.829***	-0.163	-0.056
	(0.385)	(0.255)	(0.138)	(0.051)
Observations	18,849	18,849	114,903	114,903
R-squared	0.442	0.356	0.344	0.237
Hour FE	Yes	Yes	Yes	Yes
Date FE	Yes	Yes	Yes	Yes
Flight FE	Yes	Yes	Yes	Yes

Notes: This table presents the results of regressing flight delays against the number of scheduled HSRs or number of scheduled conventional trains. Columns (1) and (2) only include flights departing from Beijing to destinations linked to HSR lines in July 2011, January 2012, June 2012, and May 2013. Columns (3) and (4) only include flights departing from Beijing to destinations linked to an ordinary Beijing-departure train in April 2009, December 2010, July 2011, January 2012, June 2012, and May 2013. The hour, date, and flight fixed effects are included in all specifications. Standard errors clustered by destinations are reported in parentheses. We use ***, **, and * to denote significance at the 1%, 5%, and 10% levels, respectively.

of HSR trains is associated with a 0.79-minute (0.83-minute) decrease in arrival (departure) delays. The results in Columns (3) and (4) show that the numbers of conventional trains are negative and not statistically significant, implying that flights do not face competition from conventional trains. Moreover, the magnitudes of the numbers of conventional trains are much smaller than those of the numbers of HSR trains, suggesting that HSR competition plays a more significant role in reducing flight delays.

These estimates show that competition from HSR lines is positively associated with improvements in flight operational efficiency. However, the results might be subject to omitted variable bias, such as unobserved pressure from the government, which leads to more intense competition and fewer flight delays. To address these endogeneity concerns, we extend our analysis of the entry of the HSR to flight routes along the Beijing–Shanghai HSR line in the empirical approach section. Specifically, we study the responses of the different measures of flight delays to the exogenous shock of the HSR entry.

Figure OA1: Unconditional relationship between competition and on-time performance



Notes: This figure shows the unconditional relationships between delays and the average number of scheduled HSR lines for September 2011, June 2012, April 2013, and January 2014. The delay is measured in four ways here: first, the monthly average arrival-delayed minutes (top left graph); second, the monthly average departure-delayed minutes (bottom left graph); third, the proportion of flights arriving 15 minutes late in a month (top right graph); and fourth, the proportion of flights departing 15 minutes late in a month (bottom right graph).