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

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Abstract

This paper analyzes the effects of high-speed rail competition on airlines' service quality (on-time performance) by utilizing a unique dataset containing all flights departing from Beijing to 113 domestic destinations in China from Jan 2009 to Dec 2012. To establish a causal interpretation of competition and quality, we employ a difference-in-difference approach with the entry of HSR serving as a plausibly exogenous shock that brings competition for the airline industry. We document two main findings in this paper. First, the entry of the HSR introduces competition to the airline industry, facilitating improvements in the on-time performance of affected flights. Second, the decrease in departure delay is identified as the source of the increase in on-time performance.

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

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

1 Introduction

An extensive body of economic research has examined the ways in which the entry of a strong competitor impacts the provision of quality products and services in a given market. Economists have identified productivity or quality improvement as a 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). However, the channels through which competition stimulates quality and the process in which competition exerts its greatest influence remain unclear due to the lack of empirical evidence. Identifying the channels and process are extremely important because it helps incumbent market participants and regulators to improve the product quality in the absence of competition. To address the literature gap, this paper examines the causal relationship between quality and competition among the inter-city transportation providers utilizing a clean source of exogenous variation in competition (faced by the airline industry): the introduction of the high-speed railway (HSR).

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 introducing HSR. On the one hand, the introduction of the HSR has exerted a positive influence on urban service industry agglomeration (Shao et al., 2017), intercity mobility (Chen, 2012; Tierney, 2012), market integration (Zheng and Kahn, 2013), population density and employment (Levinson, 2012), and, most importantly, the GDP (Ahlfeldt and Feddersen, 2017). On the other hand, some studies have revealed mis-allocation of capital on HSR infrastructures (Levinson et al., 1997) and negative externalities on small counties along HSR lines (Qin, 2017). While the growing body of literature on competition in the transport industry has provided strong evidence to show that the HSR takes market share away from airlines, leading to a steep drop in airline service frequency, airfare, and profits (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), the competition effects of the HSR on the service quality of airlines has received little empirical attention due to the lack of data on the on-time performance of flights and a clear shock triggering the competition between HSR lines and airlines.

The introduction of HSR has been regarded as the largest threat to the airline industry in the last decade for a number of reasons (Adler et al., 2010; Yang and Zhang, 2012; Fu et al., 2012; Behrens and Pels, 2012; Albalate et al., 2015). First, the HSR has become widely known for its speed and punctuality, making it a strong competitor for airlines, particularly those offering short to medium flights between metropolitan cities. Second, the market share

of domestic air traffic continues to shrink with the development of the HSR[1]. Faced with competition from the HSR, airlines in China, as well as in other countries (e.g., France and Japan), have also limited their supply by reducing the frequency on the affected routes. Third, some airlines in China have resorted to matching or beating lower HSR fares. Since price is not the main deciding factor for travelers[2]. Therefore, it is extremely important to include non-price factors such as journey time and convenience, into an analysis of the effects of competition.

In this paper, we exploit the passenger airline industry in association with the introduction of high-speed rail network in China to identify the causal relationship between competition and service quality, and pinpoint the source of potential improvement in airlines' on-time performances. We employ a unique and comprehensive dataset containing all flights departing from Beijing to 113 domestic destinations in China during the period between Jan 2009 and Dec 2012. We utilize the entry of the Beijing-Shanghai HSR on Jun 30, 2011 as a plausibly exogenous shock to the airline industry.

Studying the entry of Beijing-Shanghai HSR offers several advantages. First, the Beijing-Shanghai HSR line is both the first and the only Beijing-departure HSR line linking Beijing to other cities during the Jan 2009 to Dec 2012 sample period. The second Beijing-departure HSR line, the Beijing-Guangzhou line, began operating on Dec 26, 2012, one and a half years following introduction of the Beijing-Shanghai HSR line. Thus, our sample period allows for a clean test that is free of other Beijing-departure HSR shocks and that provides us with long pre- and post-HSR periods. Second, focusing on the Beijing-Shanghai HSR line reduces sample selection bias. The gradual expansion of China's HSR network links almost all the major Chinese cities sequentially (see Appendix Table B1), which allows the treated and non-treated cities to enter the estimation in a quasi-experimental manner, which facilitates a credible empirical analysis on the causal impact of the opening of the HSR lines on affected flights.

China is a perfect testing ground to conduct this HSR-Airline-Competition analysis for three reasons. First, the plausibly exogenous entry of HSR line introduces fierce competition to the airline industry and enables us to examine the response of service quality of affected airlines to the competition. Second, the comprehensive data available on airline on-time performance enables accurate measurements of service quality. Research shows that on-time

[1]According to the World Bank Report, intercity travelers tend to choose HSR trains over road and air options(Amos et al., 2010). Fu et al. (2012) state that the supply of airplane seats on the Wuhan–Guangzhou route dropped substantially one year after the launch of HSR lines, and all flights between Shanghai and Ningbo were canceled because of the opening of the Shanghai-Ningbo HSR line.

[2]For example, Fu et al. (2012) shows that the price of an economy class ticket for the Guangzhou-Wuhan route was reduced from 800 RMB to around 400 RMB one year after the launch of the HSR. 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).

performance is a prominent factor to shape the travelling experience, and to affect the travellers' choices on mode of transportation (Mayer and Sinai, 2003; Forbes, 2008; Goolsbee and Syverson, 2008; Prince and Simon, 2015; Gayle and Yimga, 2018). Third, given Beijing Capital International Airport's world-class capacity and notorious on-time performance as well as the China's dominant position in the HSR market, it is worth studying the competition effect of HSR entry on the service quality of airline industry so that the results can be generalized to other countries when evaluating the cost and benefits of developing an HSR network.

We conduct the empirical analysis using the two following complementary approaches Matsa (2011). We first examine the unconditional correlation between flight delays and HSR competition, which is measured by the frequency of scheduled HSR trains. The results control for an extensive set of fixed effects, including indicators for hour, date, and flight. We find that flight delays are negatively correlated with HSRs' scheduled frequency. This provides evidence to suggest that flights facing higher HSR competition experience fewer and shorter delays.

Next, to establish the causal interpretation of HSR competition and flight delays, we employ the difference-in-differences (DID) approach with the HSR entry serving as an exogenous shock that creates competition for the airline industry. Particularly, using both individual- and aggregate-level data, we compare the on-time performance of flights departing from Beijing to 11 destinations linked to the Beijing-Shanghai HSR line to that of other Beijing-departure flights. The results show that the introduction of Beijing-Shanghai HSR line leads to an average decrease of 2.53 (3.42) minutes in the individual-flight level (aggregate-level) arrival delay, and our findings survive a variety of robustness and falsification tests that support the causal inference cited.

It should be noted that the government's decision to introduce the HSR based on economic (Ahlfeldt and Feddersen, 2017), strategic (Shao et al., 2017), and lobbying (Albalate and Fageda, 2016) considerations is not a concern in identification provided such factors are independent of the flight delays. However, if there are omitted factors driving the introduction of the HSR and flight delays simultaneously, then any correlation between them could be spurious. We address the potential endogeneity concerns by including route-yearmonth fixed effects and airline-yearmonth fixed effects in order to extract the effects of opening Beijing-Shanghai HSR line from the effects of contemporaneous route-level (or destination-level) shocks and airline-level shocks. In addition, to address the possibility that flight specific shocks might also affect the service quality, we aggregate the individual-flight level data into airline-route-month level to reduce the bias in the case that flight number was changed or cancelled, as well as the issue related to outliers. Consistent with the individual-flight level regressions, the treatment effects in the aggregate-level regressions are found to be signif-

icantly negative, and the estimates controlling for either route- or airline-level shocks are consistent with the baseline results, with similar magnitudes.

Moreover, to rule out the possibility that airlines manipulate their on-time performances by lengthening the scheduled duration (the scheduled arrival time minus the scheduled departure time) to mitigate the expected delays (Mayer and Sinai, 2003; Prince and Simon, 2015), we use *ScheduledDuration* as the alternative outcome variable and find the treatment effects insignificant, suggesting that the airlines did not attempt to hide the problem of flight delays on the treated routes by extending the scheduled duration. Following Mayer and Sinai (2003) and Prince and Simon (2015), we include two additional measures of on-time performance, *TravelTime* and *ExcessiveTravelTime* (see the detailed discussion in Section 3.2), both of which are unlikely to be affected by airline scheduling. To net out variations in air traffic control and weather conditions, we use *ExcessiveTravelTime* as our primary measure of airlines' on-time performance or fight delay rate. This measure serves as a benchmark for scheduled duration that is unaffected by air congestion or weather shocks. In all cases, the on-time performance of treated flights improves more than that of non-treated flights in the post-HSR period.

Furthermore, we take a closer look at the source of improvement in on-time performance due to the competition of HSR entry. To identify the source, we break down the time factor into two discrete areas *TravelTime*: time under the control of a flight (also referred to as the *departure delay*), and time beyond the control of a flight (also referred to as the *actual duration*). As illustrated in the flowchart in Figure 2, 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), air time, and taxi-in time (time spent on the arrival runway). Our estimation results show that only the departure delay responds negatively to the introduction of the HSR, implying that a decrease in departure delays that is directly controlled by the airlines explains the improvement in on-time performance.

To address alternative explanations, we conduct several alternative analyses that examine airlines' responses through reshuffling flights or cancelling flights, and two subsample analyses that focus on the holiday period and international flights. We find that our competition argument holds true. To buttress the interpretation that competition from the HSR leads to the airlines' improved service quality, we rule out the endogeneity concern caused by the sample selection of HSR destinations by conducting a more valid comparison in our DID analysis. Specifically, we create a new control group consisting of only nine cities linked to the Beijing-Guangzhou HSR line introduced on Dec 26, 2012. More specifically, the Beijing-Shanghai HSR and Beijing-Guangzhou HSR lines were both initiated by the central government in 2008, while the latter one finished the construction one and a half years after

the opening of the Beijing-Shanghai HSR line[3]. Thus, the problem of non-random placement is much less of a concern in our comparison of the 11 treated cities and 9 control cities in the subsample analysis. 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 endogeneity of sample selection.

Moreover, our results support the underlying assumption of a common trend in the pre-treatment period for the DID approach, and provide evidence that there are no systematic differences between the treatment and control groups over time. Hence, the differences in on-time performance after the entry of the Beijing-Shanghai HSR line are a measure of the treated flights' responses to the competition shock.

We also conduct several robustness checks to strengthen our estimation. For instance, we extend our sample period up to Sep 2015 to include the introductions of other 19 HSR lines to test the generality of our research findings[4]. The results of the heterogeneity tests suggest that non-hub airlines are more responsive to competition from the HSR than hub airlines, and flights on the short- and medium-routes (air-distance within 1,200 km) are more responsive to competition from the HSR than flights on the long-routes (air-distance exceeds 1,200 km). Moreover, the falsification tests create an artificial treatment group and an artificial treatment date, and show that the effects of HSR competition are not caused by the characteristics of HSR destinations, airline industry cycle, or broader HSR network plan. Finally, we estimate the welfare gains of HSRs for travellers who continue to take airplanes, which previous studies have not calculated or included. The estimated additional gains amount to around 49.66 million CNY in 2012 for the affected one-way flights along Beijing-Shanghai HSR line, excluding passengers who switch from airplanes to HSRs.

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 details the empirical specifications and identification strategy. Section 5 presents the core results and Section 6 provides additional tests. Section 7 discusses the implications. The conclusion follows in Section 8.

[3]Both Beijing-Shanghai HSR and 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 the construction works began in 2008. Since the total length of the Beijing-Guangzhou HSR line is 2,298 km, which is around 0.5 times longer than that of the Beijing-Shanghai HSR line (1,318 km), the construction of the Beijing-Guangzhou HSR line took longer time, and the Beijing-Guangzhou HSR was put into use one and a half years after the opening of the Beijing-Shanghai HSR line.

[4]Appendix Table B1 summarizes the opening dates of all HSR lines. Many cities were connected to Beijing following completion of some of the new HSR lines. For instance, the Beijing-Guangzhou HSR line was launched on Dec 26^{th}, 2012, and the Shanghai-Kunming HSR line was launched on Sep 14^{th}, 2014.

2 Background and Literature

2.1 High-speed Rail

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 high-speed railway network in the world. Zhou et al. (2018) provide a detailed review on the development of the HSR network over time. As of mid-2018, China's HSR network has expanded to 29 provinces, reaching approximately 27,000 km (17,000 mi) in total length and accounting for about two-thirds of the world's high-speed rail tracks in commercial service. The medium-term plan[5] of the Chinese government is to expand the HSR network to 38,000 km (24,000 mi) by 2025. Based on a network plan for "eight vertical and eight horizontal", Beijing is regarded as the most important starting point of the vertical lines[6].

The Beijing-Shanghai line is the first medium- and long-haul HSR track that links Beijing to other cities along the way. Although the Beijing-Tianjin line began operating in early 2008, it is unlikely to impact any airline routes due to the short distance (120km) between these two cities[7]. 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 trips between Beijing and Shanghai, such as Routes G1 and G3, take only 4 hours and 28 minutes. Before Jun 30, 2011, the fastest train traveling from Beijing to Shanghai was a bullet train, which traveled at a maximum speed of 150-200 kph and took around 13 hours. Given that a direct flight between these cities takes only two hours, train travel was therefore a much more time-consuming option prior to Jun 30, 2011. However, the opening of the Beijing-Shanghai HSR line on Jun 30, 2011 changed the situation significantly by reducing train travel time from 13 hours to less than 5 hours.

According to Sachs (2010), HSR travelers spend 92% of their total journey time on the

[5]The plan consists of the Beijing-Shanghai line, Beijing-Hongkong line, Beijing-Harbing line, Beijing-Kunming line, Dalian-Beihai line, Baotou-Haikou line, Hohhot-Nanning line, and Lanzhou-Guangzhou line

[6]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 the HSR lines to connect almost all 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 Aug 1, 2018, 37 cities in China have been connected by HSR lines departing from Beijing.

[7]Spanning a distance of 117 km, the Beijing–Tianjin HSR line is the first Beijing-departure high-speed rail between Beijing and 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, due to the short distance, flights are not offered for the Beijing-Tianjin route. Therefore, the introduction of the Beijing–Tianjin HSR line should not affect the on-time performance of any medium- or long-distance flights departing from Beijing.

train, while air travelers spend only 62% of their total journey time on the plane, highlighting the inefficiency 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 line imposes fierce competition on flights linking Beijing to other cities along the way.

2.2 Flight Delays

Many papers attest to the fact that one of the most important dimensions of an airline's "service quality" is its on-time performance (Mazzeo, 2003; Prince and Simon, 2009; Yang and Zhang, 2012). According to the Air Travel Consumer Reports [8] published by the US Department of Transportation, flight cancellations, delays, and changes have been the most reported traveler complaints in recent years. Gayle and Yimga (2018) assert that travelers are willing to pay for $1.56 per minute to avoid arrival delays. Prince and Simon (2015) 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.

The Chinese airline industry has experienced tremendous growth in the past 30 years. According to a recent report released by the Civil Aviation Administration of China, air passenger traffic has grown from 18.2 billion in 1987 to 837.8 billion in 2016[9]. China has been the second largest airline market since 2005 and is expected to overtake the U.S. as the largest airline market by 2022[10].

Despite huge growth, China's airline market is still in its nascent stages. The poor operational efficiency and regulations have been much criticized by the public and economists. According to the 2018 world airport punctuality report[11], none of China's airports is ranked in the top 20 in terms of on-time performance. The Beijing Capital International Airport (BCIA), which became the busiest airport in Asia in terms of passenger traffic and total traffic movements in 2009, has been the world's second busiest airport in terms of passenger traffic since 2010. Ranked 6^{th} in the world, the BCIA registered 557,167 aircraft movements (take-offs and landings) in 2012. However, the BCIA has poor on-time performance for both domestic and international flights. Domestically, the BCIA ranks 44^{th} out of the 55 major airports in terms of punctuality[12] as of 2017.

Specifically, the BCIA sent out 286,602 flights in 2017, and only 53.67% of the flights departed on time (within 15 minutes of their scheduled departure times). Moreover, the

[8]Source: *https://www.transportation.gov/airconsumer/air-travel-consumer-reports*

[9]Civil Aviation Administration of China, *http://www.caac.gov.cn/XXGK/XXGK/index_172.html?fl=11*

[10]Source: *http://www.caac.gov.cn/XXGK/XXGK/TJSJ/201805/P020180521622831951125.pdf*

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

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

departure delays averaged at around 48.5 minutes[13]. In comparison, China's most punctual airport, the Xining Cao Jia Bao Airport, sent out 24,077 flights in 2017, and 78.22% of the flights departed on time; the departure delays averaged at around 23.4 minutes. The world's most punctual airport, the Osaka International Airport, sent out 74,914 flights in 2017, and 94.66% of the flights departed on time; the departure delays averaged at around 13.1 minutes. Given the coexistence of BCIA's world-class capacity and notorious on-time performance, it is worth studying the competition effect of HSR entry on the on-time performance of Beijing-departure flights.

2.3 Related Literature

This paper adds to the literature that examines the causal effects of competition on quality and productivity. While a high level of consensus has been reached in the literature on the effects of competition on pricing behavior[14], 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 positive effects of competition on productivity, while Gal-Or (1983) suggests a negative relationship. Holmes and Schmitz Jr (2010) provide a comprehensive review to fully understand the effects of competition on productivity and point to two important research requirements. First, the definition of competition must be clear. Second, the mechanism through which competition exerts influence on productivity must be identified. We contribute to this strand of the literature by analyzing variation in competition from a clean source, and by identifying an accurate mechanism for the improvement of airline service quality.

This paper 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 researchers to study how the service quality in the airline industry is affected by competition from HSR. Clear definitions of HSR competition and airline's service quality (that is on-time performance), as well as the exogenous variations in HSR competition, allow us to establish causal interpretations of competition in on-time performance. Moreover, the richness of flight data enables us to pinpoint the source of the increases in on-time performance resulting from HSR competition. This provides guidelines for airlines, airports, and governments to better

[13]The figure is calculated by using the data collected from Feichangzhun. Source: *https://data.variflight.com/analytics/OTPRankingbyAirport*

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

manage the airline industry and improve the airline efficiency even in the absence of HSR competition.

This paper contributes to yet another strand of literature on HSR. With the rapid expansion of the HSR network around the world, economists have paid a great deal of attention to the economic outcomes that are closely related to the introduction of the HSR. Shao et al. (2017) and Ahlfeldt and Feddersen (2017) exploit a DID model and find that the introduction of the HSR enhances economic development. However, some studies argue that the HSR primarily benefits large cities, not small counties (Zheng and Kahn, 2013; Qin, 2017). In addition, the HSR is found to exert positive influences on intercity mobility (Chen, 2012; Tierney, 2012), market integration (Zheng and Kahn, 2013), population density and employment (Levinson, 2012).

A number of recent studies have examined the impacts of the HSR on the airline industry. Most of the studies focus on market share and price. 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 the competition between HSR and airlines varies by travel purpose. Yang and Zhang (2012) show that both airfare and HSR fare decrease with the weight of welfare in the HSR's objective function, while airfare decreases and HSR fare increases in response to the increase of airport access time. Fu et al. (2012) provide a comprehensive analysis on whether China's airline industry can survive the growing expansion of the HSR network. In line with the competition effects of the HSR on airlines revealed in France, London, 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 entry of the HSR takes a large proportion of market share from airlines, particularly in short to medium routes linking metropolitan cities. For instance, in Mar 2010, all the flights between Zhengzhou and Xi'an were canceled after the introduction of HSR services in the area. Adler et al. (2010), Fu et al. (2012), Behrens and Pels (2012), and Yang and Zhang (2012) document that the competition between HSR lines and airlines is more fierce in medium-haul transport markets, where the travel distance is approximately 400 to 1,200 km (or the travel time is about four hours). Overall, the current literature provides abundant evidence that the HSR threatens the survival of airlines.

3 Data and Summary Statistics

3.1 Data

Using the on-time performance data provided by a leading data services company that focuses on commercial aviation, this paper examines the non-price responses of airlines to the entry

of HSR in China. The data services 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[15] during the period between Jan 2009 and Dec 2012.

In total, our dataset is comprised of 865,967 flights scheduled by 41 airlines for 113 destinations. Following Prince and Simon (2015), we define a route as a directional Beijing-destination pair for any carrier that provides non-stop service. Similarly, we restrict our analysis to non-stop service because on-time performance is measured only for individual flights. To illustrate, we consider CA1515 departing from Beijing to Shanghai as an example. Since we have only one departure airport, the BCIA, in the data, the destination city (i.e., Shanghai) also refers to a route. China Air (CA) refers to an airline company. CA1515 refers to a flight.

The dataset includes almost all the information regarding a fight, such as the 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 (air time)

Since Beijing-Shanghai HSR line began operating on Jun 30, 2011, the sample period covers a sufficient time window to study the event of HSR entry. In addition, because the Beijing-Shanghai line is the first and only Beijing-departure HSR operating during the sample period, we are able to conduct clean analyses on the effect of HSR competition on airline service quality. We summarize the HSR destinations linked to Beijing along different HSR lines in Appendix Table B1. 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. The opening of the Beijing-Shanghai HSR line on Jun 30, 2011, directly impacted 26 destinations. Among the 26 destinations, 17 destinations[16] are located along the Beijing-Shanghai HSR line. While the other 9 destinations[17] are not located along the line, they have been also linked directly to Beijing since Jun 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 turned to be available on Jun 30, 2011, because the Beijing-Shanghai HSR line became connected to the Shanghai-Hangzhou HSR line, which was introduced on Oct 26, 2010.

Flights link 113 destinations with Beijing. As shown in Figure 1, of the 113 destinations,

[15]These cities are part of China cities because some cities have no direct/indirect flight to Beijing.

[16]Langfang, Cangzhou, Dezhou, Jinan, Tai'an, Jining, Zaozhuang, Xuzhou, Suzhou (Anhui Province), Chuzhou, Nanjing, Zhenjiang, Changzhou, Wuxi, Suzhou (Jiangsu Province), Kunshan, and Shanghai

[17]Qingdao, Bengbu, Hefei, Liu'an, Hangzhou, Shaoxing, Ningbo, Quzhou, and Wenzhou

11 [18] became reachable by the Beijing-departure HSRs following introduction of the Beijing-Shanghai HSR. Therefore, the flights departing from Beijing to these 11 destinations are considered as the treatment group because they are subject to the competition pressure imposed by the introduction of Beijing-Shanghai HSR, and the rest Beijing-departure flights serve as the control group. Appendix Figure A1 presents the monthly trends of four different on-time performance measures for the treatment group and the control group from Jan 2009 to Dec 2012.

[Figure 1 inserted here]

In order to conduct a general analysis that includes the introduction of other Beijing-departure HSR lines, such as the Beijing-Guangzhou line and Tianjin-Qinhuangdao line, we extend our analysis by focusing on a longer sample period that ranges from Jan 2009 to Sep 2015. More specifically, 18 new HSR tracks operated between Dec 2012 and Sep 2015. In this period, the data is expanded to include more than 2.45 million flights and the number of treated destinations reached by Beijing-departure HSRs increased from 11 to 33. Figure 1 presents the geographic distribution of treat and control destinations for visualization. Specifically, the crossing and railway signs (including blue, black, and green ones) denote the 113 domestic destinations reached by Beijing-departure direct flights between Jan 2009 and Dec 2012. The blue railway signs represent the 11 destinations linked to the Beijing-Shanghai HSR line and consist of the treatment group. The black and green railway signs stand for the destinations linked to the Beijing-Guangzhou HSR line and other Beijing-departure HSR lines, respectively. Notably, both the Beijing-Guangzhou HSR and other Beijing-departure HSR lines were introduced after Dec 2012. Therefore, during the sample period between Jan 2009 and Dec 2012, the destinations labelled with black and green railway signs in association with the destinations labelled with crosses consist of the control group in the baseline analysis.

In addition, to isolate the impact of market competitiveness on on-time performance from that of weather conditions (Mazzeo, 2003), we collect the hourly data of weather conditions, including temperature, rainfall, and visibility at the site of BCIA for our sample period from *Wunderground*[19].

3.2 Outcome Variables: Measures of On-time Performance

Similar to studies on the threat of new entrants in the airline industry (Goolsbee and Syverson, 2008; Prince and Simon, 2015), we investigate how treated flights respond to the introduction of HSR in the on-time performance. We employ different measures of on-time

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

[19] Source: https://www.wunderground.com/

performance suggested by the literature (Mayer and Sinai, 2003; Goolsbee and Syverson, 2008; Prince and Simon, 2009, 2015). We also aggregate our individual-flight level data into airline-route-month cells. Following Prince and Simon (2009) and Prince and Simon (2015), we estimate weighted least squares models using the number of flights per airline-route in each month as the weight in respective cells. This enables us to produce the same estimates as those extracted from performing OLS on the disaggregated flight level data.

We employ three measures of on-time performance for both arrival and departure delays. *ArrDelay in minutes* is the simplest measure of on-time performance. It is the number of minutes late (or early) a flight arrives at the gate, relative to the scheduled arrival time. When we conduct the analyses at the airline-route-month level, we average the arrival delay over the airline-route during a month. *ArrDelay 15 minutes* is a dummy equal to 1 if a flight arrives at the gate at least 15 minutes late, and 0 otherwise (Prince and Simon, 2015). We can also compute the percentage of flights arriving at least 15 minutes late during a month for the analyses at airline-route-month level. *ArrDelay 30 minutes* is a dummy equal to 1 if a flight arrives at the gate at least 30 minutes late, and 0 otherwise. We also measure the fraction of flights arriving at least 30 minutes late at the aggregate level. Similarly, we use three measures to establish the departure delay, denoting them as *DepDelay in minutes*, *DepDelay 15 minutes*, and *DepDelay 30 minutes*, respectively.

Airlines can manipulate their on-time performance by adjusting the scheduled flight times to mitigate the expected delays (Mayer and Sinai, 2003; Prince and Simon, 2015). The observed improvement of on-time performance, which is measured by *arrival delays*, could be biased when airlines chose to lengthen the scheduled duration rather than improve the operational efficiency. Therefore, we introduce another two measures of on-time performance: *ActualTravelTime (ATT)* and *ExcessiveTravelTime (ETT)*. *ATT* captures the time difference between scheduled departure time and actual arrival time. *ETT* is computed as the *ATT* minus the minimum feasible actual travel time. The minimum feasible actual travel time refers to the minimum travel time of a flight observed in a given month, and serves as a benchmark for determining the travel time in the case that a flight is free of any external influences, such as air congestion and weather condition. Therefore, the *ETT* controls for any unobserved or observed time-varying external influences and is immune to airline scheduling conflicts.

To identify the source of change of on-time performance caused by the HSR entry, we then decompose the actual travel time into two parts: *departure delay* and *actual duration*. While *departure delay* measures the time spent before leaving the gate, *actual duration* includes *Taxi-out time* (time spent on the departure runway), *Airtime* (time spent in the air), and *Taxi-in time* (time spent on the arrival runway). Figure 2 provides a flow chart to illustrate the components of flight duration.

[Figure 2 inserted here]

Table 1 reports the summary statistics of different on-time performance measures and other variables related to flights on the Beijing-Shanghai HSR lines and non-Beijing-Shanghai HSR lines, with Panel A corresponding to the individual-flight level statistics and Panel B corresponding to the airline-route-month level statistics. The observations of cancelled flights are excluded, leaving us with 865,967 individual flights and 12,499 airline-route-month cells. For both treated and control flights, the average flight delays in minutes over the departure period, including *ArrDelay in minutes*, *DepDelay in minutes*, *ActualTravelTime*, and *ExcessiveTravelTime*, increase by 1 to 4 minutes in the post-HSR period. However, the increments of delays for treated flights are relatively lower than those for control flights.

[Table 1 inserted here]

4 Empirical Approach

We employ two complementary approaches to investigate the empirical relationship of competition and airline's service quality. Specifically, we first look at the correlation between the flight delays and the number of scheduled trains (either HSR or non-HSR) on a route. Then, we study the causal effect of the entry of HSR on airline's on-time performance.

4.1 Relationship between the HSR Competition and Flight Delays

To identify the competition effect of the railway industry, we first examine whether the flight delays correlate to the number of trains (either HSR or non-HSR) on a route. We manually collect the railway schedules for trains departing from Beijing to all destinations on six random days: Apr 1, 2009; Dec 16, 2010; Jul 10, 2011; Jan 1, 2012; Jun 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 (either HSR or non-HSR) by route (from Beijing to a destination) per day. The number of HSR trains on Apr 1, 2009, and Dec 16, 2010, is 0 because the first Beijing-departure HSR line was introduced on Jun 30, 2011.

Figure 3 presents the unconditional correlations of flight delays with competition from HSR lines in four different months: July 2011, Jan 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[20], and the x-axes denote the number of scheduled HSR trains per day in a month. The negative

[20] *Delayed minutes* measures 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. *Delayed rate* refers to the fraction of flights that arrive (or depart) at least 15 minutes late on a route in a month.

relationships shown in all four graphs in Figure 3 indicate that the larger the number of scheduled HSR trains on a route, the lower the number of minutes a flight on the route is delayed, and suggest that competition from the HSR prompts airlines to improve their operational efficiency.

[Figure 3 inserted here]

To control for other unobservable effects, we measure the conditional correlation between railway competition and flight delays by capturing an extensive set of fixed effects, including indicators for hour, day, and flight. Table 2 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 non-HSR trains in Columns 3 and 4. Each observation represents a particular flight in Apr 2009, Dec 2010, Jul 2011, Jan 2012, Jun 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 Jul 2011, Jan 2012, Jun 2012, and May 2013, while Columns 3 and 4 include flights on all non-HSR lines in Apr 2009, Dec 2010, Jul 2011, Jan 2012, Jun 2012, and May 2013. The coefficients on the number of HSR trains are negative and significant in Columns 1 and 2, supporting the competition argument raised in Figure 3. Specifically, one unit increase in the number of HSR trains is associated with a 0.79 (0.83) minutes decrease in arrival (depature) delays. The results in Columns 3 and 4 show that the numbers of non-HSR trains are negative and statistically insignificant, implying that flights do not face competition from non-HSR trains. Moreover, the magnitudes of the numbers of non-HSR 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.

[Table 2 inserted here]

These estimates show that competition from HSR lines is positively associated with the 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 on the entry of the HSR to flight routes along the Beijing-Shanghai line in the following section. Specifically, we study the responses of different measures of flight delays to the exogenous shock of HSR entry.

4.2 Flight Delays and HSR Entry

To examine the causal effects of HSR entry on the service quality of affected flights, we employ a DID approach and apply it to the individual-flight level and airline-route-month level estimations. This allows us to alleviate the endogeneity concerns related to the fact that competition and service quality within an industry are not only potentially mutually depen-

dent, but also potentially simultaneously affected by local attributes, such as a preferential treatment or institutional quality.

The basic specification on the individual-flight level data is as follows:

$$Delay_{i,j,d,t} = \alpha + \beta \cdot Treatment_{i,j,d} \cdot After_t + \mu_i + \delta_{hour} + \zeta_t + \epsilon_{i,j,d,t} \quad (1)$$

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. $Treatment_{i,j,d}$ is a dummy equal to 1 for flights departing from Beijing to destinations linked to the Beijing-Shanghai HSR line, and 0 otherwise. $After_t$ is a dummy, which takes the value 1 after Jun 30, 2011, and 0 otherwise. β is the interested parameter to be estimated, which captures the difference of average post-HSR delays of a treated flight, relative to post-HSR delays of a control flight. μ_i refers to the flight fixed effect (flight number), capturing unobserved factors that possibly impact flight delays at flight level, at airline company level, and at destination (route) level. For example, CA1831 departs from Beijing to Shanghai. Therefore, controlling for 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). The term δ_{hour} represents hourly fixed effects, which account for any hourly variations that may affect the flight delays, such as the hourly density of departure flights. We also include 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.

Similarly, we conduct the DID estimations at the airline-route-month level using the following specification:

$$Delay_{j,d,m} = \alpha + \beta \cdot Treatment_{j,d} \cdot After_m + \theta_j + \eta_d + \gamma_m + \epsilon_{j,d,m} \quad (2)$$

where $Delay_{j,d,m}$ is a measure of 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, destination (route) fixed effects, and yearmonth fixed effects. We estimated WLS models for aggregate-level data by weighting each observation with the number of flights in each cell.

Initially, we examine the introduction of the first Beijing-departure HSR, which was the Beijing-Shanghai HSR line, and restrict the sample period to Jan 1, 2009, through Dec 26, 2012. Generalizing our conclusions, we also extend the analysis by examining a longer period, namely Jan 1, 2009, through Sep 30, 2015. In this lengthened sample period, more Beijing-departure HSRs are covered.

Nevertheless, the Chinese government's decision to introduce HSRs was dependent on several factors, including economic (Ahlfeldt and Feddersen, 2017) and strategic consider-

ations (Shao et al., 2017) as well as lobbying (Albalate and Fageda, 2016). This is not a concern provided the factors are independent of the individual-flight level delays. However, if any factors that drive the introduction of the HSR and individual-flight level delays simultaneously are omitted, then any correlation between them could be spurious. Next, we elaborate on our identification strategy, which aims to address any omitted factors at the route (or destination), airline (or firm), and flight levels.

4.2.1 Route-level (Destination-level) Shocks

With the booming growth of many cities in China, especially those located in the metropolitan area, improving the on-time performance of the airline industry has become a priority for local governments. A more efficient airport or airline industry would enhance the city's domestic and international reputation and help to attract investors and tourists. At the same time, the introduction of HSR lines may be necessary (e.g., due to lobbying by the local government) to meet the needs of investors and tourists. For instance, the boom of Shanghai in the past decade could have motivated local governments to improve the on-time performance (service quality) of airline industry and to establish a HSR network.

In this case, finding a negative treatment effect would be a spurious outcome of an omitted variable in destinations. Fortunately, because the treatment in our paper is uniquely defined by two locations, Beijing and one of the destinations on the Beijing-Shanghai HSR line, we are able to control for such route (destination) shocks, extracting the effects of opening Beijing-Shanghai HSR line from the effects of contemporaneous route shocks.

For instance, the airline of another route running between Beijing and Chengdu was not affected by the introduction of the Beijing-Shanghai HSR line. If the on-time performance of the flights departing from Beijing for Chengdu also increase (or decrease) after Jun 30, 2011, then an increase in the on-time performance of the Beijing-Shanghai flights might not be due to the newly introduced HSR line between Beijing and Shanghai, but rather to a contemporaneous destination shock (a demand explosion). In principle, we could control for such destination (route) shocks by including a full set of destination (route) fixed effects interacted with year-month fixed effects.

At the route level, another endogeneity concern is related to the air traffic control in the post-HSR period. To elaborate the impacts of air traffic control (especially for military purpose[21]), the air traffic control data is divided into three sources or categories: (1) Beijing Airport; (2) the treated routes; and (3) the control routes. The first two categories do not affect our interpretation on the β in the equations. On the one hand, the air traffic control at

[21] As reported by Thomson Reuters: China is set to overtake the United States as the world's largest aviation market by 2024, but airlines and travellers often complain that the military can unilaterally cancel or delay commercial flights for reasons such as military exercises. Source: https://af.reuters.com/article/worldNews/idAFKBN18L0F9

Beijing Airport should impact the treat and control flights in the same way, which suggests that the treatment effect does not change. On the other hand, the air traffic control in the post-HSR period on the treat routes should render an underestimation of the β. However, the β would be overstated if the air traffic control in the post-HSR period occurred on the control routes. We address this concern through two ways. First, we include the destination (route) interacted with year-month fixed effects as mentioned above to rule out the effects stemming from the unobserved route-level air traffic control. Second, we use the international flights as an alternative control group. Since international air routes are shared by many countries, the international flights are less likely to be affected by the air traffic control.

4.2.2 Airline-level (Firm-level) Shocks

We are also able to control for airline-level (firm-level) shocks. For instance, if the on-time performance of flights on China Airline (CA) routes, which are not along the Beijing-Shanghai HSR line, also increase (or decrease) after Jun 30, 2011, then an improvement in the on-time performance of CA flights between Beijing and Shanghai might not be due to the newly introduced HSR line between Beijing and Shanghai, but rather to a contemporaneous shock at the airline level. Analogous to the construction of the route-yearmonth controls above, we account for airline-level shocks by including the airline-yearmonth fixed effects.

4.2.3 Flight-level (individual-flight level) Shocks

In addition to the route-level and airline-level shocks, shocks that are specific to a single flight might also affect the 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 (for instance, 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. Because such shocks do not affect other flights within the same destinations, they cannot be captured by the inclusion of route-yearmonth fixed effects. Similarly, since such shocks do not affect other flights within the same airline company, they cannot be absorbed by including the airline-yearmonth fixed effects.

One efficient way to deal with the possible bias is to implement the regressions using the airline-route-month level data. In particular, we aggregate our individual-flight level data into airline-route-month level. For instance, although flight CA 0000 (Beijing-Shanghai) changed its identification to CA 0123 (Beijing-Shanghai), we can still look at the variations at the airline-route-month (i.e., CA-Beijing-Shanghai-month) level before and after the entry of HSR. Therefore, the airline-route-month level regression would reduce the bias if the flight

number changes only on certain days because individual variation is averaged to a monthly basis. The aggregation can also be considered as a way to eliminate the effect of outliers.

5 Empirical Results

5.1 Core Results

As set out in Section 4, we rely upon DID estimations to examine whether the treated flights in the post-HSR period show a greater improvement in on-time performance than their non-treated peers. Specifically, we look at the sign of our estimate of the treatment effect β in Equation (1).

[Table 3 inserted here]

The main results are presented in Table 3, where Panels A, B, and C correspond to the estimations without route/airline shocks controlled, with route shocks controlled, and with airline shocks controlled, respectively. In each panel, we employ three different measures of arrival delays: *ArrDelay in minutes* (ADM), *ArrDelay 15 minutes* (ADD15), and *ArrDelay 30 minutes* (ADD30). The hour fixed effects, date fixed effects, flight fixed effects are included in all regressions. Columns 1 to 3 show that the interaction coefficients β are consistently estimated to be significantly negative. This suggests that flights experiencing competition from the HSR entry improve their quality by reducing arrival delays to a greater extent in the post-HSR period, relative to flights in the non-treated group. On average, the treatment group reduces their arrival delay time by about 2.5 minutes more. Regarding the two binary measures of arrival delay in Columns 2 and 3, the results show that the treated flights are less likely to arrive at least 15 (or 30) minutes late in the post-HSR period, relative to the non-treated flights. In particular, the treatment effect on the "15 minutes late" measure is estimated at -0.018, which is smaller than that on the "30 minutes late" measure (estimated at -0.025). The data suggests that HSR competition has a greater effect on flights with worse on-time performances.

In Panel B (Columns 4 to 6) and Panel C (Columns 7 to 9), we address the possibility of shocks at the route level (by including route-yearmonth fixed effects) and airline level (by including airline-yearmonth fixed effects). The route- and airline-yearmonth fixed effects are described in Sections 4.2.1 and 4.2.2. As shown, the coefficients of the interaction terms remain negative and statistically significant; and the magnitudes of the coefficients do not change much. Overall, the results in Panels B and C indicate that the route shocks and airline shocks do not explain away the HSR competition effects on airlines' quality.

To account for the possibility of flights cancellation, deletion, and change, we aggregate the individual-flight level data into airline-route-month cells. In Table 4, we estimated WLS

models by weighting each observation with the number of flights in each cell. Airline fixed effects, route fixed effects, and yearmonth fixed effects are included in all specifications. The delayed minutes in Columns (1) denote arrival delayed minutes averaged in the airline-route-month; and *delayed rate15* and *delayed rate30* in Columns 2 and 3 represent the probability of flights arrive at least 15 and 30 minutes late, respectively, in the the airline-route-month cells. The coefficients on the treatment are consistently negative and significant in all columns, which imply that treated flights reduce their arrival delay by more in the post-HSR period, relative to non-treated flights. Specifically, the average arrival delays of treated flights decrease by 3.4 minutes more than that of non-treated flights in the post-HSR period. Similarly, the probability of the treated flights that arrive at least 15 (30) minutes late is 2.4 (2.8) percentage lower than non-treated flights in the post-HSR period. This suggests that our baseline results are robust accounting for the flight level shocks.

[Table 4 inserted here]

5.2 A Seeming Improvement in Service Quality?

The three most frequently cited measures of on-time performance involve a comparison of the elapsed duration between *scheduled* arrival and *actual* arrival times. As argued by Mayer and Sinai (2003) and Prince and Simon (2015), airlines can manipulate a flight's on-time performance by prolonging the scheduled duration. If this were true, then the reduction in arrival delay might be the result of prolonged scheduled duration instead of actual improved quality. Also, as Mayer and Sinai (2003) and Prince and Simon (2015) assert, the time or additional time a traveler spends on the journey is the most intuitive way to measure the flight delay. Therefore, we construct two new measures of delay: *TravelTime* and *Excessive TravelTime* (see details in Section 3.2). The tests are expanded below.

5.2.1 Scheduled Flight Duration

Panel A of Table 5 reports the results using the *scheduled duration* as the dependent variable. We find that the coefficients of interaction terms are statistically insignificant in both the individual-flight level and aggregate-level regressions. The insignificant coefficients imply that airlines of the treated flights do not adjust the scheduled duration to generate a seeming improvement in on-time performance.

[Table 5 inserted here]

5.2.2 Two Alternative Measures: Travel Time and Excessive Travel Time

We use *TravelTime* and *Excessive TravelTime* as the dependent variables in replicating the estimations and report the results in Panels B and C in Table 5. Consistent with the results

in Tables 3 and 4, the estimates on the interaction terms are negative and statistically significant. The magnitudes are relatively larger than that in estimations using *ArrDelay in minutes* as the dependent variables, suggesting that the treated flights experienced a greater reduction in *TravelTime* and *Excessive TravelTime* than the non-treated flights in the post-HSR period. The results are consistent with the findings in Prince and Simon (2009) and Prince and Simon (2015), which show that *TravelTime* and *Excessive TravelTime* are more responsive to multiple contacts and competition than *ArrDelay in minutes*. The results in Table 5 reject the hypothesis that extreme weather conditions or occasional airport congestion led to the change in on-time performance and support the HSR competition argument.

5.3 The Source of Improved Quality

The results in Tables 3 to 5 suggest that in response to HSR entry, the airline industry improves its on-time performance Thus, it is worthwhile to identify which area of air travel has the greatest potential for on-time improvement, and to examine the ways in which flights and airports contribute to on-time performance. In this section, we further investigate the source of reduced delays and assess the robustness of the results. In particular, we decompose the *TravelTime* into two parts: *actual duration* and *departure delay* (see Section 3.2 for details).

5.3.1 Actual Duration

We first look at the competition effect of HSR entry on the actual duration in both the individual- and aggregate-level regressions. As shown in Panel A of Table 6, the coefficients of the interaction terms are insignificant. The results indicate that the actual duration of a treated airline does not change, relative to that of a control airline, in the post-HSR period. This suggests that the actual duration is not the source of reduction in the arrival delays of the treated flights. We then breakdown the actual duration into *Taxi-out time*, *Airtime*, and *Taxi-in time* and use them as the dependent variables. As shown in Appendix Tables B2, for all three outcome variables, the interaction terms either are significantly positive or bear no significance, suggesting that neither runway time (including both departure and arrival runways) nor airtime is the source of the decrease in the arrival delay of the treated flights.

[Table 6 inserted here]

5.3.2 Departure Delay

To further identify the source of reduced delays, we move on to examine the competition effect of HSR entry on the departure delay. As Prince and Simon (2009) state, runway time

is likely to be substantially affected by both the departure and arrival airport. The airtime usually depends on traffic congestion, wind direction, and some other unpredictable factors. However, the departure delay should be under the airline's control to some extent. The airline could reduce the departure delay by accelerating the boarding process, training the aircraft crew, and so on. This is a reflection of improvements in quality, which subsequently reduces the departure delay.

We present our results concerning the departure delay in Panel B (Columns 3 to 6) of Table 6. The outcome variable is the departure delay in minutes. As shown in Columns 3 and 4, the estimated coefficients of treatment dummy are significantly negative. The magnitudes of the coefficients, are relatively larger than those in estimations using other measures of on-time performance. For example, the treatment effect is estimated at -5.28 for departure delayed minutes in the individual-flight level analysis, compared to -2.53 for arrival delayed minutes, -4.72 for actual travel time, and -3.91 for excessive travel time. This suggests that the reduction in departure delay might be the source of improvement in on-time performance for treated flights after the HSR introduction.

As suggested by Mazzeo (2003), weather condition is a primary concern as it is likely to affect an aircraft's ability to take off on time and is beyond the control of the airport and airline. To isolate the competition effect of HSR entry on the departure delay, we control for the three most relevant weather measures: rainfall, temperature, and visibility. The results are reported in Columns 5 ani nd 6 of Table 6. Our interested estimates remain almost the same under the control of weather condition. Rainfall and temperature show significantly positive effects, while visibility presents a significantly negative impact on the departure delay.

We also use the dummy variables that measure whether the flights depart at least 15 or 30 minutes late as our dependent variables and report the regression results in Appendix Table B3. The interested estimates are consistently negative and statistically significant.

To sum up, the introduction of the Beijing-Shanghai HSR line improves the airlines' on-time performance before leaving the gate, and subsequently leads to the reduction in arrival delays. That is, we identify the reduction in departure delays as the source of improvement in the on-time performance of the treated flights in the post-HSR period. However, several competing explanations still could threaten our HSR competition argument.

First, the entry of the HSR definitely draws a proportion of travelers away from air travel. A reduction in the number of travelers boarding a flight could lead to a decrease in the departure delay. This means that the average departure delay could decrease even if airlines maintained the same level of quality. Second, an airline company might choose to permanently cancel a flight. If this canceled flight suffers from poor on-time performance, then the average delay at the airline-route-month level would also decrease. This would

contaminate our findings because the reduction in departure delay would be caused by the cancellations of flights with poor on-time performance, not by an improvement in quality. Third, the airline companies, especially the Hub airlines, could reshuffle their flight schedules and allocate flights to less congested time slots (Mayer and Sinai, 2003), i.e, midnight time, which are less likely to be affected by air congestion. This may also negatively affect the on-time performance of other non-Hub airlines. In this case, the reduction in flight delay results from schedule reshuffling rather than from quality improvement. Fourth, our estimate of the treatment effect could be overstated if the control routes suffer more severe air traffic control in the post-HSR period. We expand the examinations on the four alternative explanations below.

5.4 Alternative Explanations

5.4.1 Holiday Analysis

To assess whether a decrease in air travelers gives rise to a decrease in departure delay, we restrict our sample to include observations only around the most important holidays. Specifically, we extract the observations seven days before or after the Spring Festival, three days before or after the Mid-autumn day, and three days before or after the National Day. In China, the Spring Festival, Mid-Autumn Day, and National Day are considered as the three most important holidays, and people typically take a vacation to celebrate. During the travel peak, all modes of transportation, including airplanes, run in 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 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 on the treatment dummy in the holiday (subsample) analysis. The significantly negative coefficients of the treatment dummy shown in Table 7 verify this prediction, indicating that the shrinking number of air travelers does not explain away the competition effect of the HSR.

[Table 7 inserted here]

5.4.2 Supply Analysis

To assess the empirical relevance of the second scenario discussed above, we first look at the variation of supply. We employ the number of flights at the flight-route-month, airline-route-month and route-month level as the dependent variables. These three variables measure the monthly supply of flights. The results in Table 8 show 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. The results are consistent with findings in Fu et al. (2012), which show that the affected flights were cancelled permanently after the entry of HSR.

[Table 8 inserted here]

Since it is possible that the on-time performance of canceled flights is worse than that of continuing flights, improvements in average on-time performance after the introduction of HSR could be due to the cancellation of flights with poor on-time performance. To determine if this is the case, we re-estimate individual and aggregate models using only the continuing flights. If the reduction in delay is induced by the cancellation of flights with poor on-time performance, then the on-time performance of continuing flights should not change after the entry of HSR. The results are reported in Table 9, with Panel A corresponding to the individual-level regressions and Panel B corresponding to the aggregate-level regressions. As shown, the introduction of HSR is found to be statistically significant in reducing arrival delays, actual travel time, excessive travel time, and departure delays and insignificant in affecting actual duration. This 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 9 inserted here]

5.4.3 Schedule Reshuffling

Airlines may also improve their on-time performance by reshuffling flight schedules and allocating flights to time slots that are less impacted by air traffic congestion. Appendix Figure A3 plots the average scheduled flights at 30-minute intervals in a day before and after the introduction of the Beijing-Shanghai HSR line during the sample period between Jan 2009 and Dec 2012. While the patterns in the figure are similar, the number of flights (y-axis) increases after the introduction of the HSR.

To identify the peak and off-peak time slots, we divide the day into 24 slots throughout the day and plot the traffic volume and average departure delayed minutes in each time slot before the introduction of the Beijing-Shanghai HSR line in Appendix Figure A4. As Figure A4 shows, the departure flights scheduled for the 1am, 6am, 7am, 9am, 10am and 22-23pm slots have better on-time performance. These time slots can thus be considered better in terms of departure on-time performance. To see whether the treated airlines allocate their departure flights to better slots to improve their on-time performance in response to the introduction of the Beijing-Shanghai HSR line, we estimate Equations (1) and (2) by introducing new dependent variables. For Equation (1), we introduce a binary variable $Y_{i,j,d,t}$ equal to 1 if the flight was scheduled to a better time slot, and 0 otherwise. For Equation (2), we calculate the density of flights in the better time slots at the airline-route-month

level. If the hypothesis that the treated airlines allocate their flights to better time slots in response to the introduction of the Beijing-Shanghai HSR line were true, then we should find significantly positive estimates on the treatment dummies in estimating Equations (1) and (2). The results are reported in Table 10. As shown, the estimated coefficients of $Treatment*After$ are neither positive nor statistically significant, suggesting that the schedule reshuffling hypothesis does not hold.

[Table 10 inserted here]

5.4.4 Connecting Flights

A further competing explanation for the improved quality is that flights in the control group in the post-HSR period experience more delays created by the delays of prior flights (also called connecting flights). Therefore, the increased delays of flights in the control group in the post-HSR period may also lead to the negative estimates of β in the baseline tables. To address this issue, we focus on a sub-sample consisting of flights departing in the early morning (6am to 9am) only. The flights departing in the morning are less likely to be connecting fights. The results are reported in Table 11. The estimates of the interaction term are significantly negative in all columns, thereby suggesting that the HSR competition argument still holds.

[Table 11 inserted here]

5.5 Selection Bias

Thus far, we have compared the average post-HSR delays of flights linked to the treated destinations, relative to the post-HSR delays of flights linked to the control destinations. Since the placement of destinations on the HSR line as well as the order of HSR construction depend on numerous factors, such as local economy, industry distribution, and geographic characteristics, the estimation results discussed above are subject to endogeneity bias. Many of the destinations in our control group, such as Yulin (a third-tier city), are not comparable to the HSR destinations, such as Shanghai (a first-tier city); therefore, the non-random selection of the treatment group is a concern in our DID analysis.

To address this sampling issue and ensure a valid comparison, we create a new control group consisting of only 9 destinations[22] along the Beijing-Guangzhou HSR line introduced on Dec 26, 2012. A public report[23] (indicated by the black railway signs in Figure 1) published by the Chinese central government details that the Beijing-Shanghai and Beijing-Guangzhou HSR lines are part of the "Four Vertical and Four Horizontal" medium- and

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

[23]Source: http://www.gov.cn/fwxx/content_1784050.htm

long-term HSR network plan, the construction of which commenced in 2008. Since the Beijing-Guangzhou line spans 2,298 km, which is 0.5 times longer than the Beijing-Shanghai line (1,318 km), construction took more time and operations began one and a half years after the opening of the Beijing-Shanghai line. As shown in Figure 1 and Appendix Table B4, relative to the comparison in the original DID design in terms of economic and political status in China, the nine cities of the control group are more comparable to the 11 cities of the treatment group. Moreover, we avoid problems presented in our original DID analysis by keeping the number of treated subjects similar to the number of control subjects.

To this end, the non-random placement problem is much less of a concern when we compare the 11 treated cities to the 9 control cities in the subsample analysis. All 20 cities are linked to a Beijing-departure HSR eventually, but only 11 cities are linked to the Beijing-Shanghai HSR during the sample period between Jan 2009 and Dec 2012. Appendix Figure A2 compares the four on-time performance measures between the treatment group (cities linked to the Beijing-Shanghai HSR) and the control group (cities linked to the Beijing-Guangzhou HSR). The estimation results are reported in Table 12. Specifically, the treatment effects in the subsample analysis remain economically negative and statistically significant, suggesting that our competition argument is not threatened by the endogeneity of sample selection.

[**Table 12 inserted here**]

5.6 Common Trend and Dynamic Analyses

The OLS estimation suggests that the entry of HSR in Jun 2011 significantly improved the on-time performance of flights on the affected route. A prerequisite for the validity of DID design is that the pre-trend of outcome variables between control and treatment groups should be similar. In this section, we present a classic event study that shows the treatment effects before and after the entry of the HSR on the on-time performance of the treated flights.

Specifically, we add a new interaction term $\beta_0 \cdot Treatment \cdot Before$ to the regression specification. $Before$ 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 to the first 12 months (benchmark period 2009:01–2009:12) in our sample period, between the treatment and control groups in those 18 pre-treatment months. Similarly, the coefficients on $Treatment \cdot After$ capture the difference in the response of on-time performance after the HSR introduction compared to the first 12 benchmark months in our sample period. The validity of our DID research design requires β_0 to be statistically and economically indistinguishable from zero.

Table 13 shows estimation results on different measures of on-time performance. The

coefficients on the $Treatment \cdot After$ dummy are negative and statistically significant for all measures of on-time performance, which are consistent with the results in previous tables. However, coefficient estimates on the pretreatment period variable $Treatment \cdot Before$ are both economically and statistically insignificant. These results suggest that, prior to the entry of the Beijing-Shanghai HSR line, there were no differences in the change patterns of on-time performance between the treated and non-treated flights. This provides strong evidence to show not only that our sample of treatment and control flights is balanced and homogeneous, but also that the differences in on-time performance after the entry of the Beijing-Shanghai HSR line indeed measure the treated flights' response to the competition shock.

[Table 13 inserted here]

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

$$Delay_{i,j,d,t} = \alpha + \sum_{s=-6}^{6} \beta_s \cdot Treatment_{i,j,d} \cdot 1_{quarter\ s} + \mu_i + \delta_{hour} + \zeta_t + \epsilon_{i,j,d,t} \tag{3}$$

where $1_{quarter\ s}$ is a binary variable equal to 1 for the quarter s. The coefficient β_0 measures the immediate response in on-time performance during the HSR introduction quarter. The coefficients $\beta_1, \ldots, \beta_6$ measure the additional marginal responses one quarter, ... , and six quarters after the Beijing-Shanghai HSR entry, respectively. Similarly, coefficients$\beta_{-1}, \ldots,$ β_{-6} capture the difference of trends in on-time performance change between the treatment and the control group in each of the six pretreatment quarters.

We find that the impact of competition from the Beijing-Shanghai HSR line on the on-time performance of flights persists after entry. Figure 4 depicts the timing of the effects, with the top graph corresponding to the arrival delay in minutes and the bottom graph corresponding to the departure delay in minutes. The four graphs indicate that the treated flights start responding to competition from the Beijing-Shanghai HSR line immediately after its introduction; the response in on-time performance seems to persist.

[Figure 4 inserted here]

6 Additional Tests

6.1 Air Traffic Control on the Control Routes

Air traffic control aims to move aircraft safely and efficiently through the airspace system. If the government or the military tightens air traffic control on the non-treated routes in

the post-HSR period, our estimate of the treatment effect of HSR could be overstated. To address this issue, we utilize an alternative group consisting of routes that are less likely to be affected by Chinese government authority. This alternative group comprises international air routes. Therefore, the international flights departing from Beijing serve as a new control group in the DID estimations. Since on average international flights cost triple the time for a journey relative to domestic flights, the arrival and travel times are dependent on many external unpredictable factors. We report the results in Appendix Table B5. The coefficients of interaction term remain significantly negative and the magnitudes are greater than those in the baseline, suggesting that air traffic control on the control routes inducing overestimation is not a concern.

6.2 A General Study

For a robustness check, we expand our current study to a more general case by focusing on a longer sample period from Jan 2009 to Sep 2015. The new sample period contains 19 introductions of HSR lines (see Appendix Table B1 for details), such as the opening of the Beijing-Shanghai HSR line on Jun 30, 2011, the Beijing-Guangzhou HSR line on Dec 26, 2012, and the Tianjin-Qinhuangdao line on Dec 31, 2013. In the general study, the number of treated destinations (routes) increased from 11 to 33. The results of regressing different measures of on-time performance against the treatment dummy in the expanded sample are reported in Table 14. To be concise, we only report the regression results on the airline-route-month 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 14 inserted here]

6.3 Heterogeneity Tests

In this section, we explore the heterogeneity in the competition effects of the HSR on hub versus non-hub airlines, and short-to-medium-haul versus long-haul flights.

Hub airlines are able to tolerate greater marginal delay costs than their non-hub peers because hub airlines 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 the HSR. The dominant hub airline of the BCIA is China Air. According to a document published by the Civil Aviation Administration of China, China South Airlines, China East Airlines, Hainan Airlines, and Beijing Capital Airlines are also considered as the hub airlines of the BCIA.

Estimates of the impact of competition from the Beijing-Shanghai HSR line on the on-time performance of hub airline flights versus non-hub airline flights are presented in Panel A of Table 15. Hub is a dummy equal to 1 if the flights belong to one of the 5 hub airlines, and 0 otherwise. The estimated coefficients of $Treatment * After * Hub$ are significantly positive for all measures of on-time performance, indicating that the treatment effects are larger on non-hub airline flights than on hub airline flights. This suggests that non-hub airlines are more responsive to the HSR competition.

According to (Fu et al., 2012; Yang and Zhang, 2012), the HSR lines impose the most fierce competition for air-routes within 1,200 km. Therefore, we use 1,200km[24] as a cut-off to categorize flights into short-to-medium-haul and long-haul routes. Panel B of Table 15 presents the estimates of the impact of HSR entry on the on-time performance of the short-to-medium-haul versus long-haul routes. SM is a dummy equal to 1 if the distance between Beijing and destination is below 1,200km, and 0 otherwise. The estimated coefficients of $Treatment * After * SM$ are significantly negative for three out of four measures of on-time performance, suggesting that short-to-medium-haul flights are more responsive to competition from the HSR lines.

[Table 15 inserted here]

6.4 Falsification Tests

To test the hypothesis for possible spurious results in either geography or time, we conduct two falsification tests. The first is a placebo test where we create an artificial treatment group consisting of 9 destinations linked to Beijing-Guangzhou HSR after Dec 2012. As discussed above, although these 9 cities enter the HSR network after Dec 2012, none of the 9 destinations in the artificial treatment group were linked to Beijing-Shanghai HSR, during the sample period between Jan 2009 and Dec 2012. This addresses whether the difference we see in the original DID regressions above reflects HSR competition or just a more general effect related to characteristics of HSR destinations.

The second placebo test examines whether the original DID effects above just reflect more general time patterns, either as part of the airline industry cycle or resulting from the broader HSR network planning, that affected destinations deferentially. To do this, we create an artificial treatment date. Specifically, we proxy the introduction of the Beijing-

[24] According to Sachs (2010), the optimal operational efficiency of HSR trains is three to four hours of travel, with the 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.

Shanghai HSR line as occurring one-year prior to when they actually occurred, and have both one-year pre- and one-year post- periods lie in the period prior to actual introduction of Beijing-Shanghai HSR.

The regression results on placebo treatment group and placebo treatment date are reported in Appendix Tables B6 and B7, respectively. In both placebo tests, we find estimated coefficient of the interaction terms not statistically different from zero. This is supportive of the results we observe above being because of the difference in HSR introduction across destinations and not characteristics of HSR destinations or airline industry cycle or resulting from the broader HSR network planning.

7 Discussions

7.1 Welfare Analysis

Home to the largest HSR network (60% of the world's total as of 2016), China manages high-speed railways that cover 24,000 km (15,000 miles). The HSR network's rapid rate of expansion presents an enormous challenge for Chinese airlines to implement effective planning and response strategies to deal with the potential customer churn. A look at 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 benefit change due to decreased delays in response to the HSR entry. Following Li et al. (2007), we calculate the the flight delay cost (V_p) of additional hour for a passenger. The formulas is given as follow:

$$V_p = \beta * \frac{Wage}{2000}$$

where $Wage$ denote the yearly average salary. According to the data released by the National Bureau of Statistics[25], the yearly average salary in 2012 in Beijing is 62,676 CNY. The denominator, 2000, represents the total efficient working hours in a year[26]. β is a parameter that measures the relative time value across different types of travellers. It is a function of transport mode choice and purpose of travel. In Yang and Zhang (2012)'s paper, the time value of business passengers is set three times as large as that of leisure passengers. We then set the β in our paper at 3. So far, the cost (V_p) for an air traveller due to one additional hour (minute) delay is estimated at 94.01 CNY (1.56 CNY).

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

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

Given that our estimated reduction in arrival delay for the treated flights is 2.5 minutes ex-post the Beijing-Shanghai HSR line, the simple estimate of per guest welfare gain from the reduced arrival delay in 2012 is 2.5*1.56=3.9 CNY. Notably, this is an underestimation of the welfare gain for the treated air travelers because it does not take into account the decrease in airfare caused by the entry of the HSR. To give a more intuitive image of the welfare gain for air travelers in the affected routes, we use flights along the Beijing-Shanghai HSR route for illustration. In our data, there are 90,962 flights flying from Beijing to the 11 HSR cities in 2012. Suppose that each flight has 200 seats on average and an occupancy rate of 70%, the total welfare gain for air travelers on the affected routes in 2012 is calculated as 90,962*200*0.7*3.9=49.66 million CNY.

7.2 Other Consequences of Competition

This paper does not estimate the effects of the entry of the HSR on airfares or airline revenues. The primary reason is that the flight-level real-time price data and the airline-route-level revenue data are not available. In addition, the negative effect of competition on price is not surprising and has been studied by Goolsbee and Syverson (2008) and Yang and Zhang (2012). However, given the issue of notorious flight delays in China, perhaps more attention could be given to the effects on on-time performance.

7.3 Policy Implications

In this paper, we find that the introduction of the HSR imposed pressure on the treated airlines to improve quality by reducing flight delays. Our results have important implications for not only airlines but also countries assessing the cost and benefits of developing an HSR network.

First, our results suggest that the on-time performance of flights can be improved through greater efforts by airlines to ensure that the processes of baggage loading/unloading, check-in, and boarding proceed smoothly for all passengers. Since airlines and airports are in direct control of these processes, they should encourage feedback to management and strengthen cooperation between departments rather than blame flight delays on poor weather conditions and airport systems.

Second, in addition to the intuitionistic benefits, such as the clustering of economic activities, increased mobility of human capital and knowledge, and enhanced urban accessibility, our study reveals that the introduction of the HSR leads to improved quality in the airline industry. Moreover, our study sheds light on the cost and benefits of ongoing HSR planning processes.

8 Conclusion

The introduction of China's HSR offers travelers a fast and reliable method of transportation. Given their efficiency and reliability, the new HSR lines are expected to take market share away from other transport modes, such as air carriers and conventional trains. The fact that flight delays are extremely costly both for passengers and for airlines conveys the urgent need for additional research in this area. The threat of customer churn may prompt traditional transport service providers to improve their quality or offer more competitive pricing.

In this paper, we exploit the entry of HSR into various destinations to examine the quality response of air transportation services using a dataset that contains information on all the flights departing from Beijing. The dataset is unique as it provides details on flight timeliness that can be used to measure the service quality of airline and the disaggregated microdata enables us to examine the variation in flight timeliness across different airlines and destinations.

We use a DID strategy to establish the causal interpretation of competition on quality and examine the possibility of endogeneity and omitted shocks at both route- and airline-level. Using both individual- and aggregate-level data, we examine the competition effect of the Beijing-Shanghai HSR line by comparing the on-time performance of the flights departing from Beijing to destinations linked to the Beijing-Shanghai HSR line with flights departing from Beijing to other destinations before and after the introduction of the Beijing-Shanghai HSR line. After controlling for route and airline fixed effects, the specific timing of entry of HSR lines represents an exogenous shock to the competitive landscape of intercity transportation services. Our main analysis focuses on the sample period between Jan 2009 and Dec 2012, during which the Beijing-Shanghai HSR turns out to be the first and only medium- to long-haul Beijing-departure HSR. This enables us to execute cleaner tests. The validity of the common trend assumption required by a DID analysis is largely confirmed as there were no preexisting differences in on-time performance between treated and non-treated flights before the opening of HSR lines. The sampling selection issue is addressed by conducting a more valid comparison between the 11 treated destinations and 9 control destinations.

Our analysis shows that competition from the HSR significantly improves the quality and efficiency of air transportation services. Specifically, airlines on routes facing competition from HSR lines decreased their arrival delays by an average of 2.5 minutes, in the post-HSR period. The effects are persistent and robust to the inclusion of various fixed effects, suggesting that the improvements in the operational efficiency of air transportation services are not attributable to changes at the airline-level shocks, local market shocks, or adjustments in supply that may have followed the entry of the HSR lines. By decomposing the actual travel time and replicate the estimations, we find that the decrease in departure delay turns out to

be the source of improvement in on-time performance. Our HSR competition argument are clear of four alternative explanations, including deletion of inferior flights, supply decrease, schedule reshuffling, and delays of prior flights. The heterogeneity tests show that non-hub airlines and airlines on routes within 1,200 km distance are more responsive to the HSR competition. The results of falsification tests are supportive of our HSR competition argument as the results with either an artificial treatment group or an artificial treatment date show none statistical significance. At last, we perform a welfare analysis and reveal that total welfare gain for air travelers on the affected one-way flights along Beijing-Shanghai HSR line in 2012 is calculated as 90,962*200*0.7*3.9=49.66 million CNY.

Though focusing on the impacts of the HSR on air transportation services in China, this analysis has implications for other countries that are considering or already developing an HSR network. This empirical study confirms that the response of air transportation providers to competition from the HSR is to improve the on-time performance of their flights.

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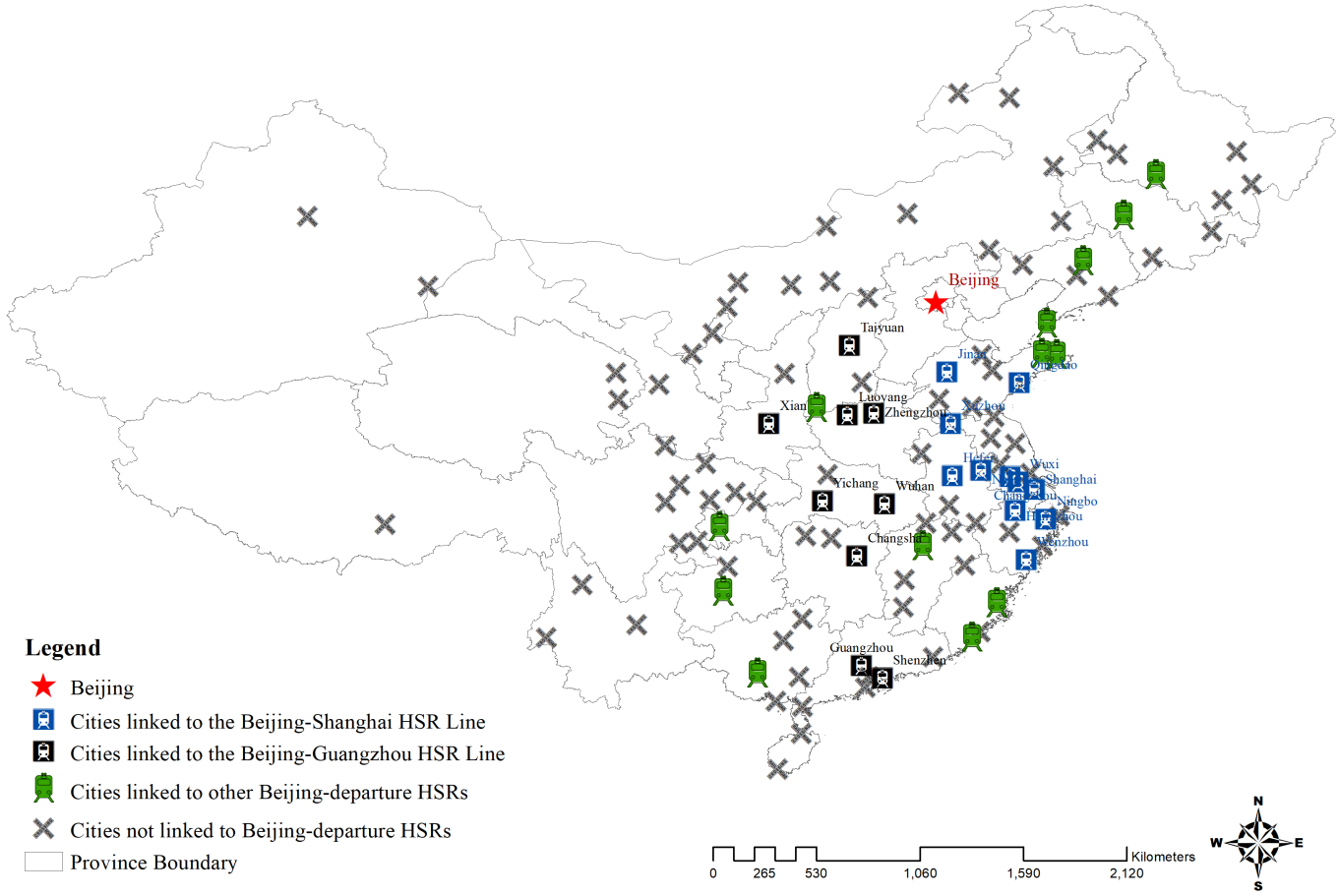
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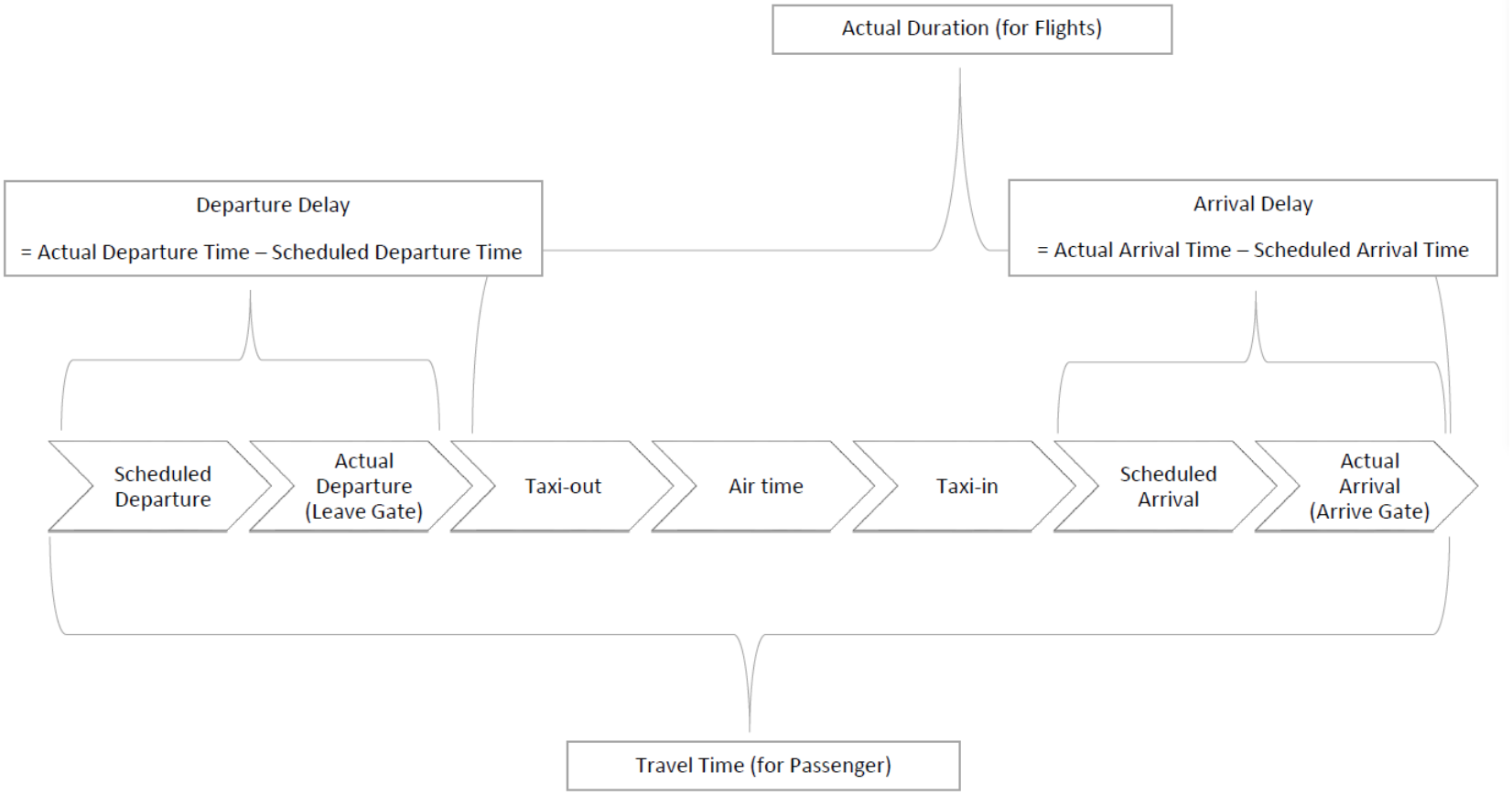
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Figure 1: Geographic Distribution of Sample Cities as of Sep 2015



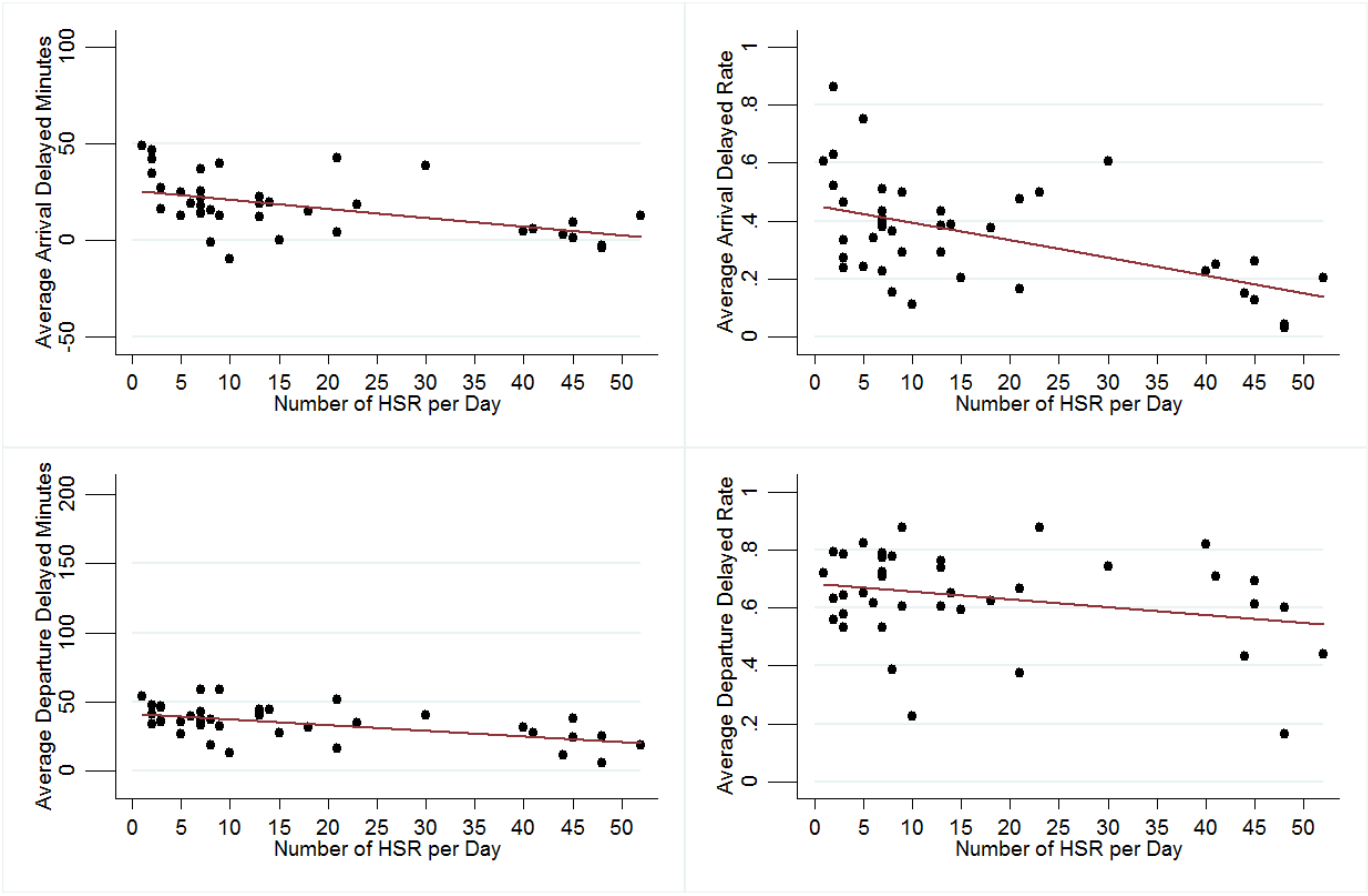
Notes: This figure presents the geographic distribution of sample destinations as of Sep 2015. The blue railway signs denote 11 treated destinations linked to Beijing-Shanghai HSR line, which is introduced on Jun 30th, 2011. The black railway signs denote 9 destinations linked to Beijing-Guangzhou HSR line, which is introduced between Dec 26th, 2012. The green railway signs denote 13 destinations linked to other Beijing-departure HSR lines, which are introduced between Dec 26th, 2012 and Sep 30th, 2015. The crosses denote destinations not linked to any Beijing-departure HSRs during our sample period. All destinations in this figure are linked by direct flights departing from Beijing.

Figure 2: A Flow Chart for Flight Delays



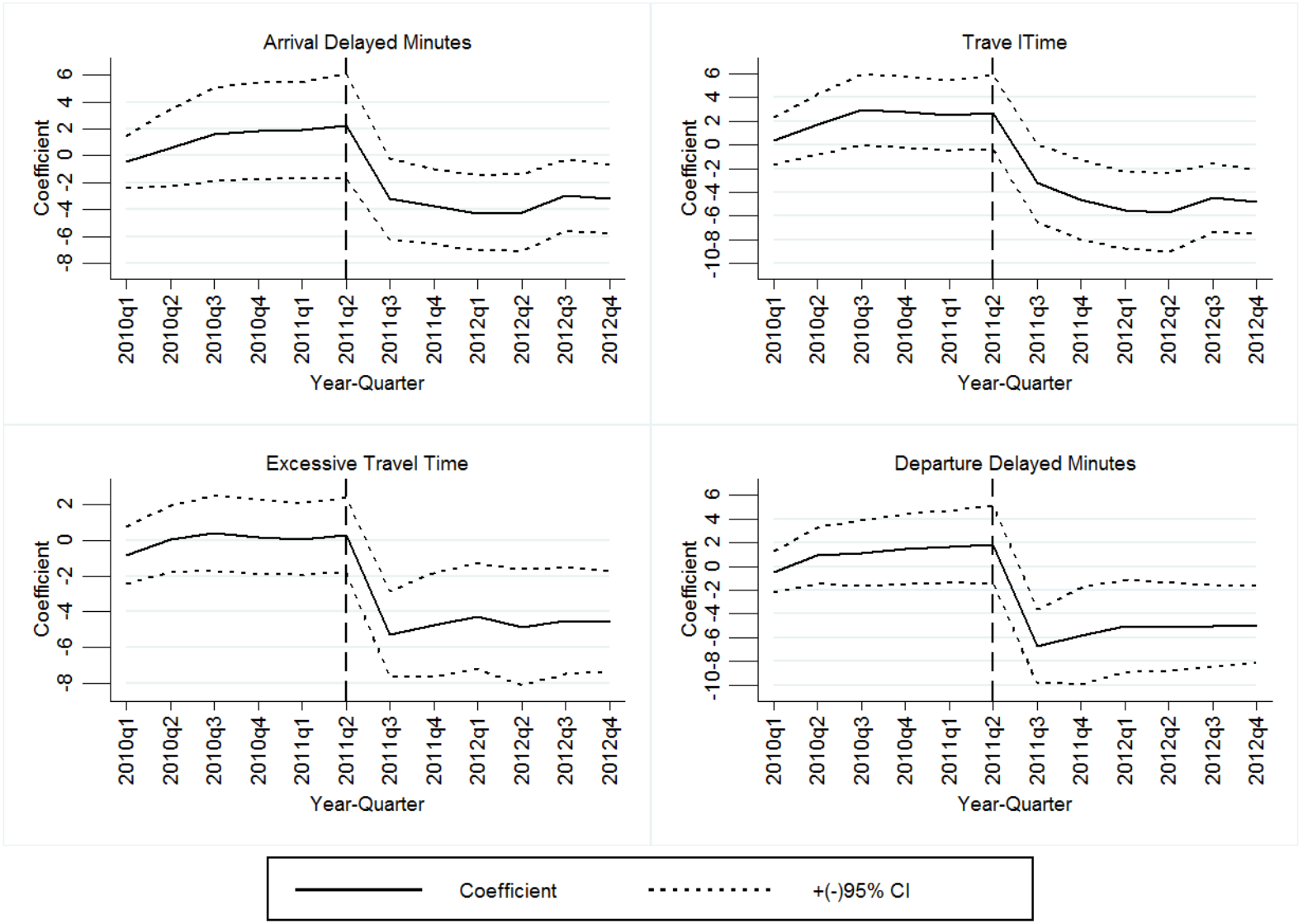
Notes: The flow chart illustrates the components of flight departure and arrival delays. *TravelTime*(denotes as ATT in the tables) captures the time difference between *scheduled departure time* and *actual arrival time*. *Departure Delay* is calculated as the time spent before leaving the gate (the difference between *Actual Departure Time* minus *Scheduled Departure Time*), and *Arrival Delay* the difference between *Actual Arrival Time* minus *Scheduled Arrival Time*. *Actual Duration* consists of the *Taxi-out time* (time spent on the departure runway), airtime, and *Taxi-intime* (time spent on the arrival runway).

Figure 3: Unconditional Relationship between Competition and On-time Performance



Notes:This figure shows the unconditional relationships between delay and average number of scheduled HSR for Sep, 2011, Jun, 2012, Apr, 2013, and Jan, 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 arrives 15 minutes late in a month (top right graph); fourth, the proportion of flights departure 15 minutes late in a month (bottom right graph).

Figure 4: Dynamic Changes of Four On-time Performance Measures



Notes: This figure plots the dynamic responses of four on-time performance to the introduction of Beijing-Shanghai HSR line. The coefficients are obtained from estimating Equation (3).

Table 1: Summary Statistics

Panel A. Individual-Flight Level Statistics

	Treated				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
ArrDelay15	0.26	0.44	0.28	0.45	0.35	0.48	0.37	0.48
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
DepDelay15	0.68	0.47	0.74	0.44	0.66	0.47	0.74	0.44
DepDelay30	0.35	0.48	0.4	0.49	0.33	0.47	0.41	0.49
TravelTime	129.65	49.09	131.21	43.3	158.17	66.74	166.58	68.51
Excessive TravelTime	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	

Panel B. Airline-Route-Month Level Statistics

ArrDelay in minutes	18.31	15.46	17.08	13.43	20.57	16.93	20.99	15.27
ArrDelay15	0.14	0.15	0.21	0.17	0.18	0.2	0.29	0.21
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
DepDelay15	0.36	0.3	0.62	0.24	0.35	0.31	0.65	0.23
DepDelay30	0.18	0.18	0.33	0.19	0.18	0.18	0.35	0.2
TravelTime	129.05	26.62	128.84	24.92	154.34	51.39	160.63	52.48
Excessive TravelTime	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	1,644		1,232		7,080		5,478	

Notes: This table presents the summary statistics of for the variables we used in the paper. Sample includes all Beijing-departure flights between Jan 1st, 2009 and Dec 26th, 2012. Panel A refers to individual flight statistics and Panel B refers to airline-route-month statistics. The definitions and constructions of these variables are discussed in detail in Section 3.2.

Table 2: Delayed Minutes and Competition

Dep. Variables	Number of HSR		Number of non-HSR	
	ADM	DDM	ADM	DDM
	(1)	(2)	(3)	(4)
Number of HSR	-0.791**	-0.829***		
	(0.385)	(0.255)		
Number of non-HSR			-0.163	-0.056
			(0.138)	(0.051)
Constant	39.624**	15.502*	35.943***	17.738
	(18.184)	(8.384)	(2.607)	(16.987)
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 HSRs or number of non-HSRs. Columns 1 and 2 only include flights departing from Beijing to destinations linked to the HSR line in Jul 2011, Jan 2012, Jun 2012, and May 2013. Columns 3 and 4 only include flights departing from Beijing to destinations linked to an ordinary Beijing-departure train in Apr 2009, Dec 2010, Jul 2011,Jan 2012, Jun 2012, and May 2013. 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% level, respectively.

Table 3: The Effects of HSR to Arrival Delays at individual-flight level

Dep. Variables	Panel A: Basic Results			Panel B: With Route Shocks			Panel C: With Airline Shocks		
	ADM	ADD15	ADD30	ADM	ADD15	ADD30	ADM	ADD15	ADD30
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Treatment*After	-2.539***	-0.018***	-0.025***	-3.413***	-0.024***	-0.031***	-1.947***	-0.018***	-0.025***
	(0.230)	(0.002)	(0.002)	(0.243)	(0.002)	(0.002)	(0.241)	(0.002)	(0.002)
Constant	-8.646**	0.123***	0.039	-60.528	-0.001	0.031	6.202	0.208	0.121
	(4.044)	(0.045)	(0.037)	(14.005)	(0.152)	(0.131)	(11.681)	(0.124)	(0.106)
Observations	865,967	865,967	865,967	865,967	865,967	865,967	865,967	865,967	865,967
R-squared	0.266	0.225	0.196	0.274	0.235	0.203	0.272	0.229	0.200
Hour FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Date FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Flight FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Airline-YearMonth FE	No	No	No	No	No	No	Yes	Yes	Yes
Route-YearMonth FE	No	No	No	Yes	Yes	Yes	No	No	No

Notes: This table reports the results of estimating Equation (1). ADM is short for short for Arrival Delayed in Minutes. ADD15 is a dummy that equals 1 if a flight arrives at the gate at least 15 minutes late, and 0 otherwise. ADD30 is a dummy that equals 1 if a flight arrives at the gate at least 30 minutes late, and 0 otherwise. Sample period is from Jan 2009 to Dec 2012. Hour, date, and flight fixed effects are included in all specifications. The route dummy interacted with YearMonth dummy are included in Panel B (Columns 4-6) and the airline dummy interacted with YearMonth dummy are included in Panel C (Columns 7-9). Standard errors clustered by destinations are reported in parentheses. We use ***, **, and * to denote significance at the 1%, 5%, and 10% level, respectively.

Table 4: The Effects of HSR to Arrival Delays at Aggregated Level

Dep. Variables	Delayed Minutes (1)	Delayed Rate15 (2)	Delayed Rate30 (3)
Treatment*After	-3.419**	-0.024*	-0.028***
	(1.441)	(0.014)	(0.011)
Constant	7.908***	0.213***	0.099***
	(1.611)	(0.020)	(0.011)
Observations	12,499	12,499	12,499
R-squared	0.610	0.677	0.640
YearMonth FE	Yes	Yes	Yes
Airline FE	Yes	Yes	Yes
Route FE	Yes	Yes	Yes

Notes: This table reports the results of estimating WLS models based Equation (2), weighting each observation by the number of flights in each cell. The delayed minutes in Columns (1) denote arrival delayed minutes averaged in the airline-route-month; and delayed rate15 and delayed rate30 in Columns 2 and 3 represent the proportion of flights arrive at least 15 and 30 minutes late, respectively, in the the airline-route-month cells. Sample period is from Jan 2009 to Dec 2012. YearMonth, 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% level, respectively.

Table 5: The Effects of HSR Introduction on scheduled duration, travel time and excessive travel time

Dep. Variables	Panel A: Scheduled Duration		Panel B: Actual Travel Time		Panel C: Excessive Travel Time	
Sample	Individual	Aggregate	Individual	Aggregate	Individual	Aggregate
	(1)	(2)	(3)	(4)	(5)	(6)
Treatment*After	0.819	-0.770	-4.726***	-5.300***	-3.919***	-4.628***
	(0. 941)	(0.777)	(0. 236)	(1.217)	(1.240)	(1.195)
Constant	121.753***	133.540***	112.960***	142.372***	15.459***	27.983***
	(0.734)	(0.836)	(4.151)	(1.031)	(3.524)	(0.871)
Observations	865,967	12,499	865,967	12,499	865,967	12,499
R-squared	0.976	0.991	0.636	0.958	0.208	0.530
Hour FE	Yes	No	Yes	No	Yes	No
Date FE	Yes	No	Yes	No	Yes	No
YearMonth FE	No	Yes	No	Yes	No	Yes
Flight FE	Yes	No	Yes	No	Yes	No
Airline FE	No	Yes	No	Yes	No	Yes
Route FE	No	Yes	No	Yes	No	Yes

Notes: This table reports the results of estimating the effects of HSR introduction on scheduled duration, travel time, and excessive travel time. The individual and aggregate level regressions are conducted in each panel. Sample period is from Jan 2009 to Dec 2012. Hour, date, and flight fixed effects are included in individual regressions. YearMonth, airline and route fixed effects are included in aggregate regressions. Standard errors clustered by destinations are reported in parentheses. We use ***, **, and * to denote significance at the 1%, 5%, and 10% level, respectively.

Table 6: The Effects of HSR Introduction on Actual Duration and Departure Delay

Dep. Variables	Panel A: Actual Duration		Panel B: Departure Delay			
Sample	Individual	Aggregate	Individual	Aggregate	Individual	Aggregate
			Without Weather Controlled		With Weather Controlled	
	(1)	(2)	(3)	(4)	(5)	(6)
Treatment*After	0.391	-0.413	-5.282***	-5.445***	-5.296***	-5.445***
	(0. 541)	(0.883)	(0. 224)	(1.723)	(0.223)	(1.723)
Rainfall					18.774***	4.991***
					(0.272)	(0.620)
Temperature					0.545***	1.935***
					(0.022)	(0.292)
Visibility					-0.004	-4.425***
					(0.008)	(0.637)
Constant	114.979 ***	125.863***	-3.978	26.646***	-8.708**	60.620***
	(1.319)	(0.494)	(3.921)	(0.947)	(3.928)	(4.907)
Observations	865,967	12,499	865,967	12,499	865,967	12,499
R-squared	0.929	0.982	0.254	0.613	0.259	0.613
Hour FE	Yes	No	Yes	No	Yes	No
Date FE	Yes	No	Yes	No	Yes	No
YearMonth FE	Yes	Yes	Yes	Yes	Yes	Yes
Flight FE	Yes	No	Yes	No	Yes	No
Airline FE	No	Yes	No	Yes	No	Yes
Route FE	No	Yes	No	Yes	No	Yes

Notes: This table reports the results of estimating the effects of HSR introduction on actual duration and departure delay. The individual and aggregate level regressions are conducted in each panel. Sample period is from Jan 2009 to Dec 2012. Hour, date, and flight fixed effects are included in individual regressions. YearMonth, airline and route fixed effects are included in aggregate regressions. Three weather measures are included in Columns 5 and 6. Standard errors clustered by destinations are reported in parentheses. We use ***, **, and * to denote significance at the 1%, 5%, and 10% level, respectively.

Table 7: Holiday Analysis

Dep. Variables	ADM	Actual Travel Time	Excessive Travel Time	DDM
	(1)	(2)	(3)	(4)
Treatment*After	-1.628**	-3.558***	-2.001**	-2.505***
	(0.798)	(0.838)	(0.826)	(0.781)
Constant	21.461**	130.406***	35.438***	20.400***
	(8.406)	(8.302)	(8.115)	(7.768)
Observations	54,701	54,701	54,701	54,701
R-squared	0.266	0.700	0.202	0.239
Hour FE	Yes	Yes	Yes	Yes
Date FE	Yes	Yes	Yes	Yes
Flight FE	Yes	Yes	Yes	Yes

Notes: This table reports the results of estimating Equation (1) on a subsample, which includes observations 7 days before/after the Spring Festival, 3 days before/after the Mid-Autumn Day, and 3 days before/after the National Day. ADM is short for short for Arrival Delayed in Minutes; and DDM is short for Departure Delayed in Minutes. Sample period is from Jan 2009 to Dec 2012. 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% level, respectively.

Table 8: The Effects of HSR Introduction on Supply

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)
Constant	3.163***	3.887***	4.380***
	(0.020)	(0.023)	(0.028)
Observations	47,620	15,434	4,751
R-squared	0.557	0.869	0.959
YearMonth 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 HSR introduction on flights supply. The 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. YearMonth fixed effects are included in all specifications. Flight fixed effects are included in Column 1; and 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% level, respectively.

Table 9: Analysis on Survival Flights

Panel A. Regressions on individual-flight level Sample

Dep. Variables	Arrival Delay	Actual Travel Time	Excessive Travel Time	Actual Duration	Departure Delay
	(1)	(2)	(3)	(4)	(5)
Treatment*After	-2.579***	-4.717***	-3.975***	0. 447	-5.374***
	(0.230)	(0.236)	(0.233)	(0.472)	(0.229)
Constant	-6.209	115.311***	17.573***	115.348***	0.101
	(4.514)	(4.372)	(4.188)	(1.405)	(4.249)
Observations	716,304	716,304	716,304	716,304	716,304
R-squared	0.262	0.637	0.205	0.929	0.253
Hour FE	Yes	Yes	Yes	Yes	Yes
Date FE	Yes	Yes	Yes	Yes	Yes
Flight FE	Yes	Yes	Yes	Yes	Yes

Panel B. Regressions on Aggregate Level Sample

Dep. Variables	Arrival Delay	Actual Travel Time	Excessive Travel Time	Actual Duration	Departure Delay
	(1)	(2)	(3)	(4)	(5)
Treatment*After	-3.419**	-5.300***	-4.628***	0.141	-5.443***
	(1.441)	(1.217)	(1.195)	(0.772)	(1.726)
Constant	7.908***	142.372***	27.983***	120.997***	26.659***
	(1.611)	(1.031)	(0.871)	(0.756)	(0.947)
Observations	12,499	12,499	12,499	12,499	12,499
R-squared	0.610	0.958	0.530	0.986	0.613
YearMonth FE	Yes	Yes	Yes	Yes	Yes
Airline FE	Yes	Yes	Yes	Yes	Yes
Route FE	Yes	Yes	Yes	Yes	Yes

Notes: This table includes flights existed both before and after the introduction of Beijing-Shanghai HSR. Panel A reports the results of estimating the effects of HSR introduction on arrival delay, actual travel time (ATT), excesive travel time (ETT), actual duration, and departure delay at the individual-flight level; and Panel B focuses on the estimation results on aggregate level. Hour, date, and flight fixed effects are included in all specifications in Panel A. YearMonth, 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% level, respectively.

Table 10: Schedule Reshuffle

Sample	Individual	Airline-Route-Month
Dep. Variables	Preferred Dummy	Monthly Preferred Rate
	(1)	(2)
Treatment*After	-0.021	-0.020
	(0.019)	(0.021)
Constant	0.212***	0.187***
	(0.012)	(0.016)
Observations	865,967	15,434
R-squared	0.781	0.595
Date FE	Yes	No
YearMonth FE	No	Yes
Flight FE	Yes	No
Airline FE	No	Yes
Route FE	No	Yes

Notes: This table examines whether affected airlines are more likely to allocate their flights to preferred time zones *ex-post* the introduction of 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. Date and flight fixed effects are included in Column 1; YearMonth, 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% level, respectively.

Table 11: Regressions on the Sample of Flights Departing between 6am and 9am

Dep. Variables	ADM	Actual Travel Time	Excessive Travel Time	DDM
	(1)	(2)	(3)	(4)
Treatment*After	-1.057**	-1.992***	-0.993**	-2.717***
	(0.419)	(0.425)	(0.417)	(0.401)
Constant	-17.708***	122.943***	7.730***	3.412
	(2.931)	(2.846)	(2.918)	(2.807)
Observations	216,782	216,782	216,782	216,782
R-squared	0.318	0.692	0.268	0.330
Hour FE	Yes	Yes	Yes	Yes
Date FE	Yes	Yes	Yes	Yes
Flight Route FE	Yes	Yes	Yes	Yes

Notes: This table focuses on a sub-sample consisting of flights departing in the early morning (6am to 9am) only. 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% level, respectively.

Table 12: Beijing-Shanghai HSR Line versus Beijing-Guangzhou HSR Line

Dep. Variables	ADD	ADR15	ADR30	ATT	ETT	DDM	DDR15	DDR30
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Treatment*After	-2.614**	-0.033***	-0.030***	-4.501***	-3.164***	-3.612***	-0.026*	-0.030***
	(1.257)	(0.011)	(0.008)	(1.184)	(1.032)	(1.152)	(0.014)	(0.011)
Constant	4.678***	0.109***	0.055***	133.124***	27.709***	26.214***	0.266***	0.120***
	(0.888)	(0.009)	(0.006)	(1.034)	(1.226)	(0.909)	(0.010)	(0.009)
Observations	4,438	4,438	4,438	4,438	4,438	4,438	4,438	4,438
R-squared	0.698	0.723	0.704	0.952	0.653	0.695	0.678	0.643
YearMonth FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Airline FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Route FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Notes: This table reports the results of estimating the HSR competition effects in subsample. Sample period is from Jan 2009 to Dec 2012. The treatment group includes flights departing from Beijing to 11 destinations linked to Beijing-Shanghai HSR line. The control group includes flights departing from Beijing to 9 destinations linked to Beijing-Guangzhou HSR line after Dec 2012. The estimations are conducted at the airline-route-month level. ADD is short for average arrival delayed minutes, ADR15 is short for arrival delayed rate15 and ADR30 is short for arrival delayed rate30. ATT is short for actual travel time and ETT is short for excess travel time. YearMonth, 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% level, respectively.

Table 13: Common Trend

Dep. Variables	Arrival Delayed Minutes (1)	Actual Travel Time (2)	Excess Travel Time (3)	Departure Delayed Minutes (4)
Treatment*Before	-0.005	0.300	-0.942	1.340
	(1.335)	(1.341)	(0.697)	(0.916)
Treatment*After	-3.205**	-4.582***	-5.294***	-3.822**
	(1.551)	(1.664)	(1.404)	(1.520)
Constant	9.359***	142.441***	28.659***	27.350***
	(1.628)	(1.355)	(1.124)	(1.262)
Observations	12,499	12,499	12,499	12,499
R-squared	0.514	0.932	0.393	0.535
YearMonth FE	Yes	Yes	Yes	Yes
Airline FE	Yes	Yes	Yes	Yes
Route FE	Yes	Yes	Yes	Yes

Notes: This table examines common trend assumption in the DID analysis. Sample period is from Jan 2009 to Dec 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, and 0 otherwise. The estimations are conducted at the airline-route-month level. YearMonth, 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% level, respectively.

Table 14: General Study

Dep. Variables	ADD	ADR15	ADR30	ATT	ETT	DDM	DDR15	DDR30
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Treatment*After	-3.848*	-0.038**	-0.035***	-2.150*	-2.406**	-1.345	-0.023**	-0.029***
	(2.155)	(0.015)	(0.011)	(1.166)	(0.932)	(1.026)	(0.009)	(0.008)
Constant	19.493***	0.233***	0.117***	142.943***	29.252***	26.976***	0.489***	0.218***
	(4.780)	(0.018)	(0.010)	(1.295)	(0.998)	(1.278)	(0.019)	(0.014)
Observations	28,991	28,991	28,991	28,991	28,991	28,991	28,991	28,991
R-squared	0.346	0.489	0.459	0.890	0.362	0.517	0.642	0.580
YearMonth FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Airline FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Route FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Notes: This table reports the results of estimating the HSR competition effects in an extended sample. Sample period is from Jan 2009 to Sep 2015. The number of treated destinations increased from 11 to 33 as of Sep 2015. The estimations are conducted at the airline-route-month level. ADD is short for average arrival delayed minutes, ADR15 is short for arrival delayed rate15 and ADR30 is short for arrival delayed rate30. ATT is short for actual travel time and ETT is short for excess travel time. YearMonth, 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% level, respectively.

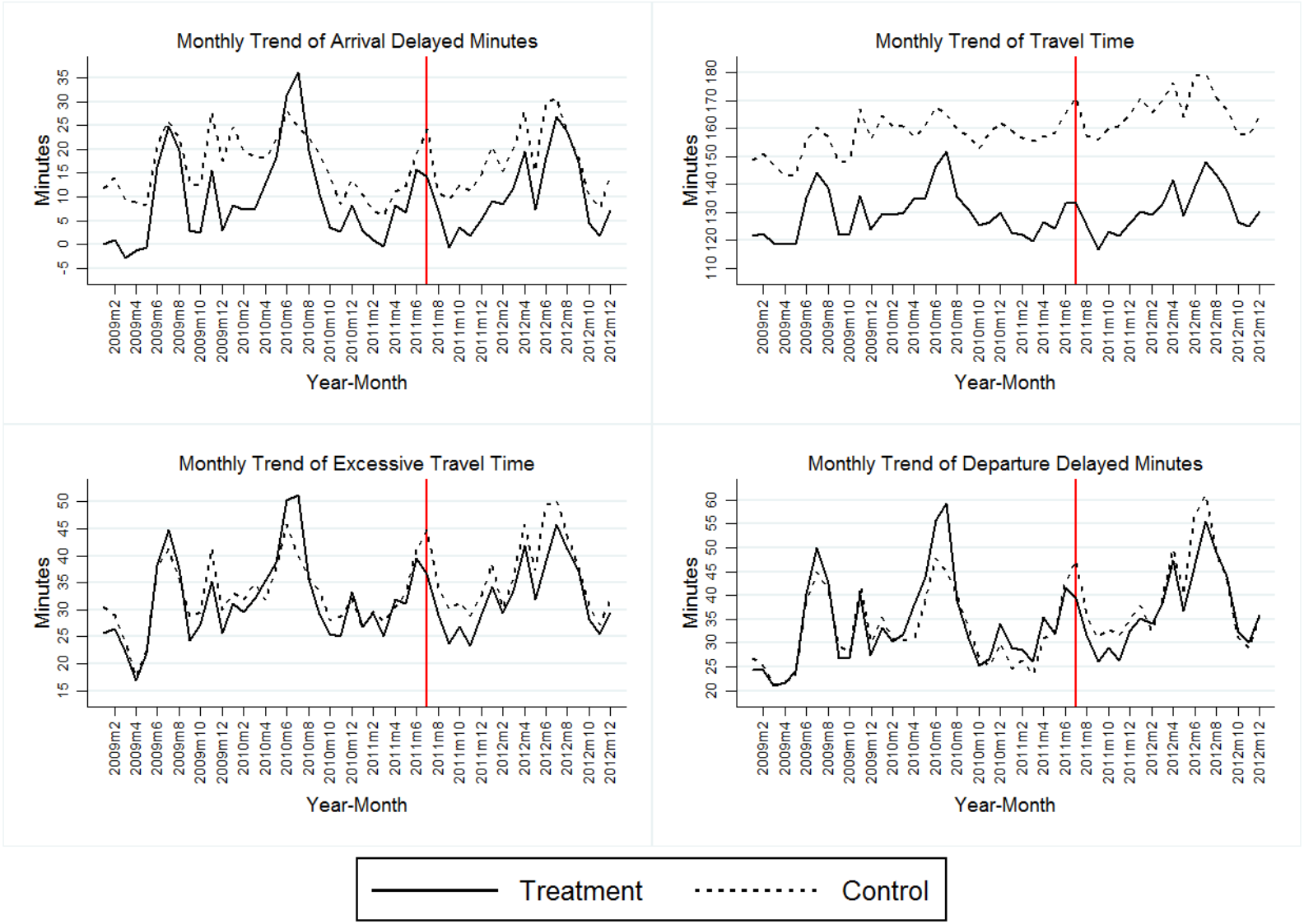
Table 15: Heterogeneity Tests

Dep. Variable	Panel A. Hub Airlines Heterogeneity				Panel B. Distance Heterogeneity			
	ADM	ATT	ETT	DDM	ADM	ATT	ETT	DDM
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Treatment*After	-5.532***	-2.669***	-3.251***	-0.904	-3.696**	-0.889	-0.556	2.074***
	(1.335)	(0.724)	(0.564)	(0.648)	(1.831)	(0.967)	(0.843)	(0.689)
Treatment*After*Hub	3.379**	1.081**	1.671***	0.970*				
	(1.343)	(0.550)	(0.427)	(0.512)				
Treatment*After*SM					-0.252	-1.825*	-2.737***	-3.656***
					(1.868)	(1.025)	(0.891)	(0.759)
Constant	19.619***	142.985***	29.314***	27.011***	19.494***	142.954***	29.266***	26.994***
	(4.632)	(1.232)	(0.990)	(1.210)	(4.620)	(1.224)	(1.002)	(1.203)
Observations	28,991	28,991	28,991	28,991	28,991	28,991	28,991	28,991
R-squared	0.346	0.890	0.362	0.516	0.346	0.890	0.363	0.517
YearMonth FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Airline FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Route FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Notes: This table examines the heterogeneity in HSR's 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. SM is a dummy equal to 1 if the distance between Beijing and destination is below 1200km, and 0 otherwise. ADM is short for short for Arrival Delayed in Minutes. ATT is short for actual Travel Time. ETT is short for Excessive Travel Time. DDM is short for short for Departure Delayed in Minutes. The estimations are conducted at the airline-route-month level. YearMonth, 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% level, respectively.

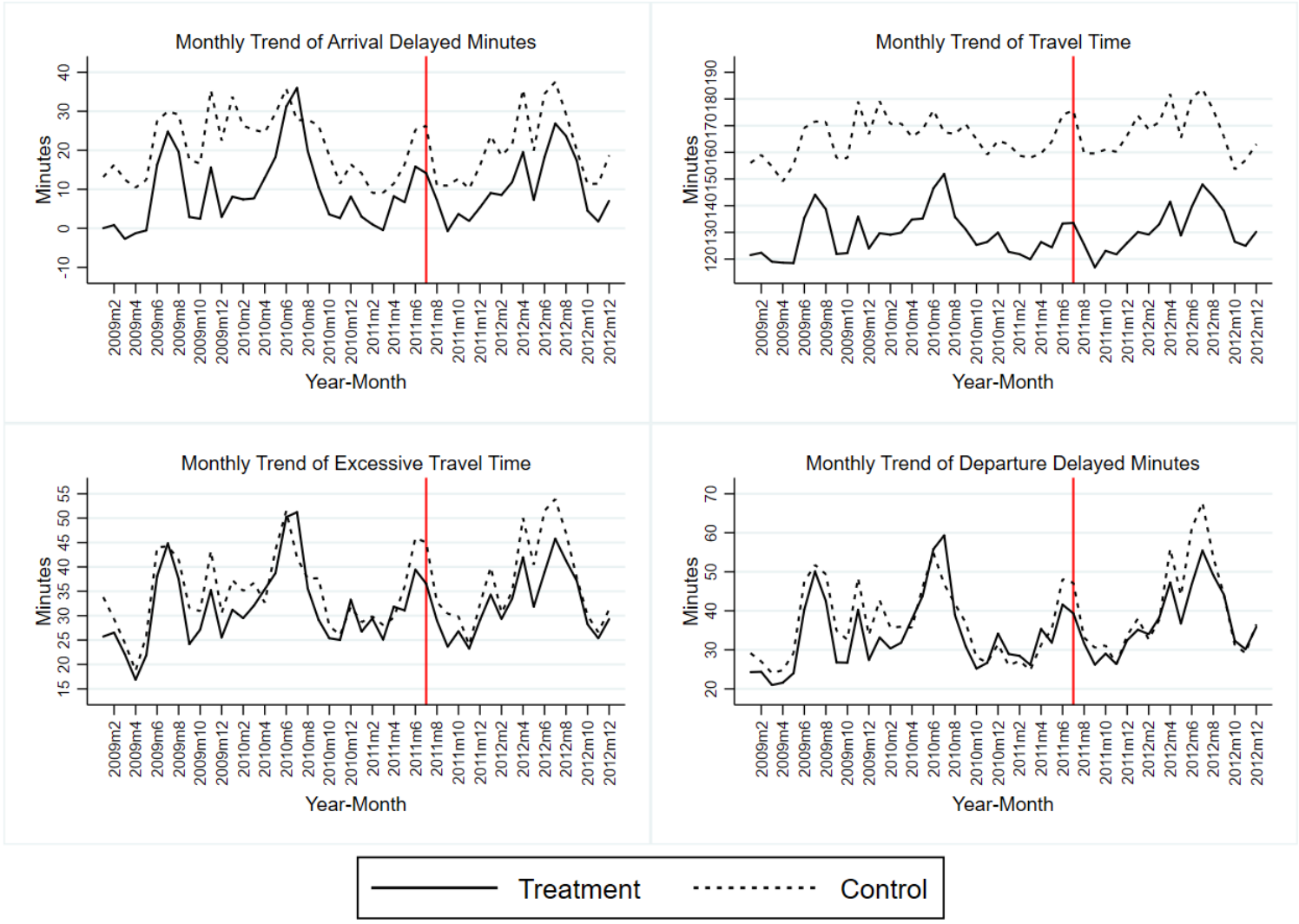
APPENDICES

Figure A1: Monthly Trends of On-time Performance Measures for 11 Treated and 102 Control Destinations



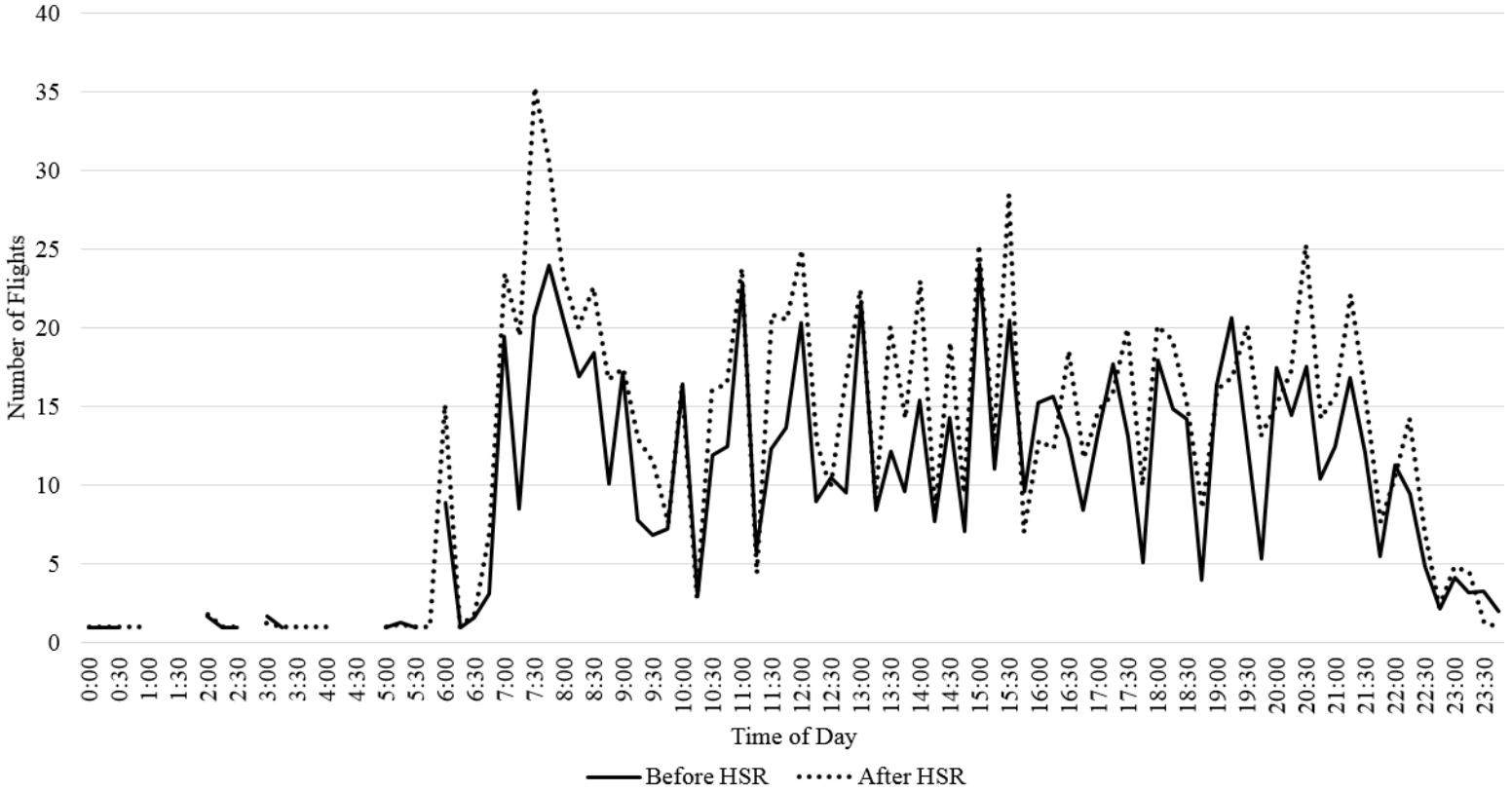
Notes: This figure plots the monthly trends of four measures of on-time performance for treated and control groups. The treated group refers to the flights departing from Beijing to 11 destinations denoted by the blue railway signs in Figure 1. The control group refers to the flights departing from Beijing to 102 destinations denoted by the black railway signs, green railway signs and crosses in Figure 1.

Figure A2: Monthly Trends of On-time Performance Measures for 11 Treated and 9 Control Destinations



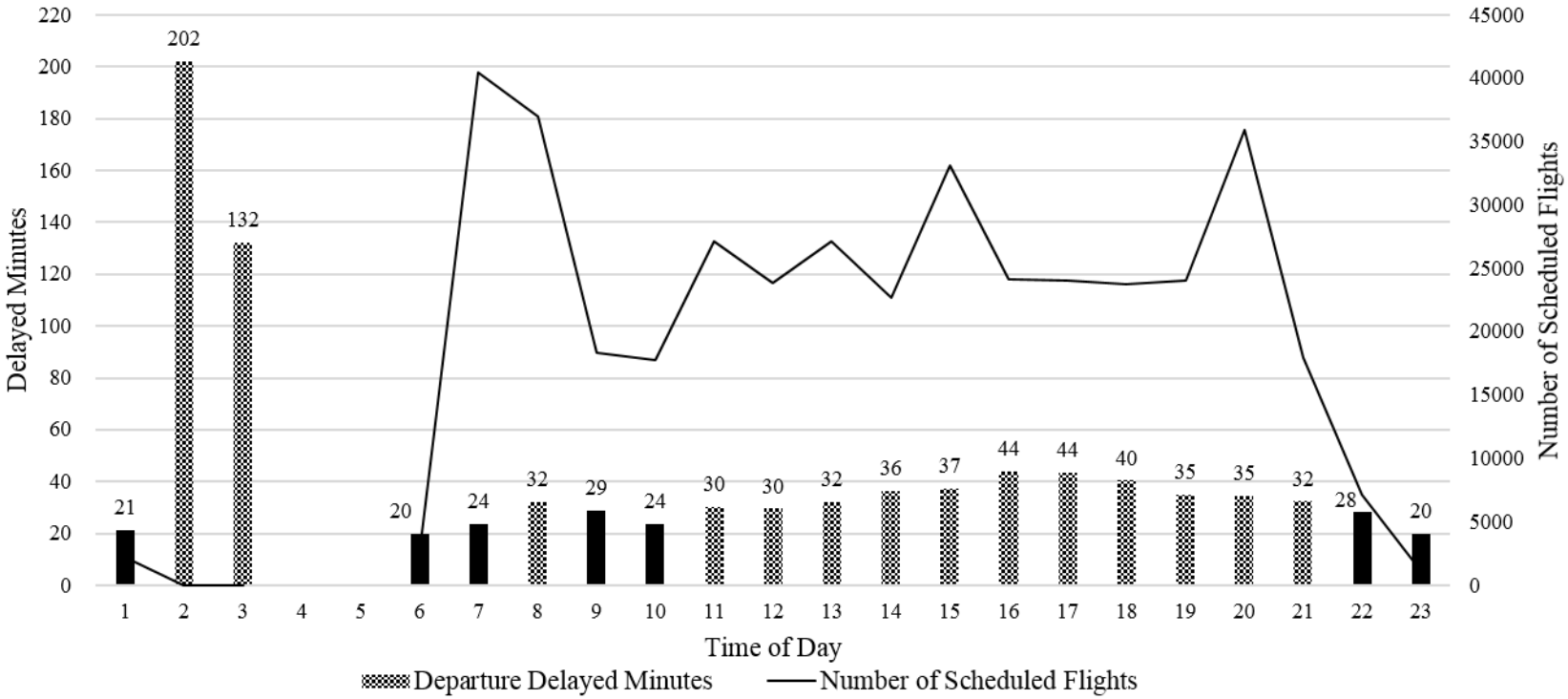
Notes: This figure plots the monthly trends of four measures of on-time performance for treated and control groups. The treated group refers to the flights departing from Beijing to 11 destinations denoted by the blue railway signs in Figure 1. The control group refers to the flights departing from Beijing to 9 destinations denoted by the black railway signs in Figure 1.

Figure A3: The Distributions of Schedule Time Slots before/after the HSR Introduction



Notes: This figure plots the distributions of schedule time slots before/after the HSR Introduction. The solid line represents the distribution of scheduled flights before Beijing-Shanghai HSR introduction and the dotted line represents the distribution of scheduled flights before Beijing-Shanghai HSR introduction.

Figure A4: Distribution of Departure Delay Throughout the Day



Notes: This figure plots the distributions of flights by hour before the introduction of Beijing-Shanghai HSR on Jun 30, 2011. The solid line represents the average departure delayed minutes by hour. The bar represents the number of total flights by hour, with the solid bar denoting the preferered time slots.

Table B1: HSR Cities Linked with Beijing

City	Province	Travel Time	Distance	Entry 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 B1 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 summarize the cities linked with Beijing by different HSR lines before Sep tember, 2015. It also reports the province a HSR city belongs to, the travel time by HSR departing from Beijing to a HSR city, the distance in kilometers, the entry date, and the official name of the HSR line.

Table B2: The Effects of HSR to Taxi-in/out Time at individual-flight level and Aggregate Level

Sample	Individual			Airline-Route-Month		
Dep. Variables	Taxi-out Time	Taxi-in Time	Airtime	Taxi-out Time	Taxi-in Time	Airtime
	(1)	(2)	(3)	(4)	(5)	(6)
Treatment*After	0.117	-1.389***	1.740***	0.383	-0.562	2.876**
	(0.086)	(0.055)	(0.124)	(0.272)	(0.370)	(1.390)
Constant	11.572***	17.787***	92.367***	17.650***	15.806***	84.827***
	(1.514)	(0.976)	(2.188)	(0.282)	(0.166)	(0.466)
Observations	865,387	865,387	865,387	12,499	12,499	12,499
R-squared	0.097	0.141	0.813	0.477	0.455	0.973
Hour FE	Yes	Yes	Yes	No	No	No
Date FE	Yes	Yes	Yes	No	No	No
YearMonth FE	No	No	No	Yes	Yes	Yes
Flight FE	Yes	Yes	Yes	No	No	No
Airline FE	No	No	No	Yes	Yes	Yes
Route FE	No	No	No	Yes	Yes	Yes

Notes: This table reports the results of estimating the effects of HSR introduction on taxi-out time, taxi-in time, and airtime. The individual and aggregate level regressions are conducted in each panel. Sample period is from Jan 2009 to Dec 2012. Hour, date, and flight fixed effects are included in individual regressions. YearMonth, airline and route fixed effects are included in aggregate regressions. Standard errors clustered by destinations are reported in parentheses. We use ***, **, and * to denote significance at the 1%, 5%, and 10% level, respectively.

Table B3: The Effects of HSR to Delayed Departure at Least 15/30 Minutes at Individual and Aggregate Levels

Sample	Individual				Airline-Route-Month			
Dep. Variables	ADD15		ADD30		ADR15		ADR30	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Treatment*After	-0.030***	-0.034***	-0.030***	-0.035***	-0.027**	-0.043*	-0.027**	-0.043*
	(0.002)	(0.002)	(0.002)	(0.002)	(0.012)	(0.025)	(0.012)	(0.025)
Rainfall			0.080***	0.127***			0.044***	0.059***
			(0.003)	(0.003)			(0.010)	(0.006)
Temperature			0.001***	0.001			0.015***	0.023***
			(0.000)	(0.004)			(0.004)	(0.003)
Visibility			0.001	0.001			0.011	-0.039***
			(0.008)	(0.001)			(0.011)	(0.006)
Constant	-0.133***	-0.040	-0.145**	-0.071***	0.256***	0.113***	0.250***	0.434***
	(0.043)	(0.045)	(0.043)	(0.045)	(0.009)	(0.008)	(0.086)	(0.049)
Observations	865,387	12,499	865,387	12,499	865,387	12,499	865,387	12,499
R-squared	0.197	0.209	0.198	0.211	0.679	0.640	0.679	0.640
Hour FE	Yes	Yes	Yes	Yes	No	No	No	No
Date FE	Yes	Yes	Yes	Yes	No	No	No	No
YearMonth FE	No	No	No	No	Yes	Yes	Yes	Yes
Flight FE	Yes	Yes	Yes	Yes	No	No	No	No
Airline FE	No	No	No	No	Yes	Yes	Yes	Yes
Route FE	No	No	No	No	Yes	Yes	Yes	Yes

Notes: This table reports the results of estimating the effects of HSR introduction on other measures of arrival delays. The individual and aggregate level regressions are conducted in each panel. Sample period is from Jan 2009 to Dec 2012. Hour, date, and flight fixed effects are included in individual regressions. YearMonth, airline and route fixed effects are included in aggregate regressions. Standard errors clustered by destinations are reported in parentheses. We use ***, **, and * to denote significance at the 1%, 5%, and 10% level, respectively.

Table B4: Comparison of Treated and Control Groups before Beijing-Shanghai HSR Entry

	Treated		Control1		Control2		Treated-Control1	Treated-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*
TravelTime	123.29	25.67	146.85	48.59	144.54	44.54	-23.56***	-21.25**
Excessive TravelTime	32.37	6.82	33.41	10.35	33.47	5.67	-1.04	-1.10

Notes: Treated refers to the 11 destinations linked to the Beijing-Shanghai HSR line. Control 1 refers to the 102 destinations not linked to the Beijing-Shanghai HSR line. Control 2 refers to the 9 destinations linked to the Beijing-Guangzhou HSR line.

Table B5. International Flights in the Control Group

Sample	Delayed Minutes	Delayed Rate15	Delayed Rate30
	(1)	(2)	(3)
Treatment*After	-3.850*	-0.030**	-0.044**
	(2.024)	(0.015)	(0.021)
Constant	25.355***	0.466***	0.189***
	(1.516)	(0.025)	(0.016)
Observations	2,446	2,446	2,446
R-squared	0.703	0.559	0.616
YearMonth FE	Yes	Yes	Yes
Airline FE	Yes	Yes	Yes
Route FE	Yes	Yes	Yes

Notes: This table reports the results of estimating the effect of HSR introduction on departure delays with the control group consisting of international flights. YearMonth 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% level, respectively.

Table B6: Placebo Test 1 of an Artificial Treatment Group

Dep. Variables	ADD	ADR15	ADR30	ATT	ETT	DDM	DDR15	DDR30
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Treatment*After	0.416	-0.008	-0.006	0.046	-0.593	-2.102	-0.002	0.001
	(1.619)	(0.021)	(0.013)	(1.219)	(1.048)	(1.320)	(0.021)	(0.016)
Constant	11.051***	0.134***	0.065***	148.406***	29.560***	27.959***	0.260***	0.119***
	(1.920)	(0.012)	(0.007)	(1.600)	(1.288)	(1.499)	(0.012)	(0.009)
Observations	10,203	10,203	10,203	10,203	10,203	10,203	10,203	10,203
R-squared	0.509	0.592	0.553	0.936	0.382	0.529	0.688	0.652
YearMonth FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Airline FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Route FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Notes: This table reports the results of a placebo test by creating an artificial treatment group consisting of 9 destinations linked to Beijing-Guangzhou HSR introduced on Dec 26, 2012. The destinations in the artificial treatment group were not linked to Beijing-Shanghai HSR, during the sample period between Jan 2009 and Dec 2012. In this regression, the 11 actual treated destinations linked to Beijing-Shanghai HSR before Dec 2012 are excluded. Hour, date, and flight fixed effects are included in individual regressions. YearMonth, airline and route fixed effects are included in aggregate regressions. Standard errors clustered by destinations are reported in parentheses. We use ***, **, and * to denote significance at the 1%, 5%, and 10% level, respectively.

Table B7: Placebo Test 2 of an Artificial Treatment Date

Dep. Variables	ADD	ADR15	ADR30	ATT	ETT	DDM	DDR15	DDR30
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Treatment*After	2.366	0.013	0.008	1.420	0.086	1.011	0.007	0.017
	(1.985)	(0.015)	(0.009)	(1.587)	(1.145)	(1.752)	(0.023)	(0.017)
Constant	9.394***	0.121***	0.059***	141.522***	28.154***	26.904***	0.252***	0.112***
	(1.444)	(0.008)	(0.005)	(1.278)	(1.061)	(1.273)	(0.008)	(0.006)
Observations	6,129	6,129	6,129	6,129	6,129	6,158	6,129	6,129
R-squared	0.498	0.649	0.606	0.921	0.384	0.540	0.695	0.655
YearMonth FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Airline FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Route FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Notes: This table reports the results of a placebo test by creating an artificial treatment date. This treatment date is placed at a point (on Jun 30, 2010) one year before the introduction (on Jun 30, 2011) of Beijing-Shanghai HSR. The pre- and post-HSR periods are then set as one year before and after the artificial treatment date, Jun 30, 2010. Hour, date, and flight fixed effects are included in individual regressions. YearMonth, airline and route fixed effects are included in aggregate regressions. Standard errors clustered by destinations are reported in parentheses. We use ***, **, and * to denote significance at the 1%, 5%, and 10% level, respectively.