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

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Abstract

This study analyzes the effects of high-speed rail competition on airlines' service quality (on-time performance) using a unique dataset containing the details of all flights departing from Beijing to 113 domestic destinations in China since January 2009. To establish a causal relation between competition and service quality, we employ a difference-in-differences approach, with the entry of high-speed rail serving as a plausibly exogenous shock that offers competition to the airline industry. We document two main findings. First, the entry of high-speed rail creates competition for the airline industry, facilitating improvements in the on-time performance of the 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 Codes: 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 affects the provision of quality products and services in a given market. Economists have identified productivity or quality improvement in response to competition in different industries and countries (Hörner, 2002; Haskel et al., 2007; Goolsbee and Syverson, 2008; Holmes and Schmitz Jr, 2010; Topalova and Khandelwal, 2011; Matsa, 2011; Prince and Simon, 2015). However, the channels through which competition stimulates quality and the process in which competition exerts its greatest influence remain unclear because of the lack of empirical evidence. Identifying the channels and process is extremely important because it helps incumbent market participants and regulators improve product quality in the absence of competition. To bridge this gap in the literature, this study examines the causal relationship between quality and competition among intercity transportation providers using a clean source of the exogenous variation in competition (faced by the airline industry): the introduction of high-speed rail (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 HSR positively influences the agglomeration of the urban service industry (Shao et al., 2017), intercity mobility (Chen, 2012; Tierney, 2012), market integration (Zheng and Kahn, 2013), population density and employment (Levinson, 2012), and, most importantly, GDP (Ahlfeldt and Feddersen, 2017). On the other hand, some studies have revealed the misallocation of capital on HSR infrastructure (Levinson et al., 1997) and negative externalities on small counties along HSR lines (Qin, 2017). While the growing body of literature on competition in the transport industry has provided strong evidence that HSR takes market share away from airlines, leading to a steep drop in the frequency, airfares, and profits of airline services (Park and Ha, 2006; Adler et al., 2010; Behrens and Pels, 2012; Fu et al., 2012; Yang and Zhang, 2012; Jiang and Zhang, 2014; Albalate et al., 2015), the competition effects of HSR on the service quality of airlines has received little empirical attention because of the lack of data on the on-time performance of flights and a clear shock triggering the competition between HSR lines and airlines.

The introduction of HSR has been regarded as the largest threat to the airline industry in the past 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, HSR has become 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 HSR[1]. Faced with competition from 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], it is extremely important to include non-price factors such as journey time and convenience in an analysis of the effects of competition.

In this study, we exploit the passenger airline industry in association with the introduction of the HSR network in China to identify the causal relationship between competition and service quality and pinpoint the source of potential improvement in airlines' on-time performance. We employ a unique and comprehensive dataset containing the details of all flights departing from Beijing to 113 domestic destinations in China between January 2009 and September 2015. We use the entry of the Beijing–Shanghai HSR on June 30, 2011 as a plausibly exogenous shock to the airline industry.

Studying the entry of the 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 January 2009 to December 2012 sample period. The second Beijing-departure HSR line, the Beijing–Guangzhou line, began operating on December 26, 2012, 18 months after the introduction of the Beijing–Shanghai HSR line. Thus, our sample period allows for a clean test free of other Beijing-departure HSR shocks, which thereby 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 most major Chinese cities sequentially (see Table B1 in the Appendix), which allows the treated and non-treated cities to enter the estimation in a quasi-experimental manner. This approach thus facilitates a credible empirical analysis of the causal impact of the opening of HSR lines on the 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 lines provides fierce competition to the airline industry and enables us to examine the response of affected airlines to such competition in terms of service quality. Second, the comprehensive data available on airline on-time performance enable the accurate measurement of service quality. Research shows that on-time performance is a prominent factor in shaping the traveling experience and

[1]According to a 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) show that the price of an economy class ticket for the Guangzhou–Wuhan route was reduced from RMB 800 to around RMB 400 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).

affecting travelers' choices of mode of transportation (Mayer and Sinai, 2003; Forbes, 2008; Goolsbee and Syverson, 2008; Prince and Simon, 2015; Gayle and Yimga, 2018). Third, given the world-class capacity and poor on-time performance of Beijing Capital International Airport (BCIA) as well as China's dominant position in the HSR market, it is worthwhile studying the competition effect of HSR entry on the service quality of the airline industry to generalize the results to other countries when evaluating the cost and benefits of developing an HSR network.

We conduct the empirical analysis using two 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 high-speed railways' scheduled frequency, which suggests that flights facing higher HSR competition experience fewer and shorter delays.

Next, to establish whether a causal relation exists between 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. In particular, 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 with that of other Beijing-departure flights. The results show that the introduction of the Beijing–Shanghai HSR line leads to an average decrease of 2.53 (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.

The government's decision to introduce HSR is based on economic (Ahlfeldt and Feddersen, 2017), strategic (Shao et al., 2017), and lobbying (Albalate and Fageda, 2016) considerations, rather than the on-time performance of airlines in a region. However, if omitted factors are driving the introduction of HSR and flight delays simultaneously, then any correlation between them could be spurious. We address the potential endogeneity concerns by including route-year-month fixed effects and airline-year-month fixed effects to extract the effects of opening the Beijing–Shanghai HSR line from the simultaneous effects of route-level (or destination-level) and airline-level shocks. In addition, to address the possibility that flight-specific shocks might also affect service quality, we aggregate the individual flight-level data at the airline-route-month level to reduce the bias in the case that flight number was changed or canceled 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 significantly 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 performance

by lengthening the scheduled duration (the scheduled arrival time minus the scheduled departure time) to mitigate expected delays (Mayer and Sinai, 2003; Prince and Simon, 2015), we use *ScheduledDuration* as an alternative outcome variable and find the treatment effects to be non-significant, suggesting that the airlines did not attempt to hide the problem of flight delays on 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 flight 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 examine the source of the improvement in on-time performance due to the competition created by HSR entry. To identify the source, we divide 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, the departure delay is calculated as the time spent before leaving the gate (the actual departure time minus the scheduled departure time) and the actual duration consists of the taxi-out time (time spent on the departure runway), airtime, and taxi-in time (time spent on the arrival runway). Our estimation results show that only the departure delay responds negatively to the introduction of the HSR, implying that a decrease in departure delays directly controlled by the airlines explains the improvement in on-time performance.

To provide alternative explanations, we conduct several alternative analyses that examine airlines' responses by rescheduling or canceling flights and two subsample analyses that focus on the holiday period and international flights. We find that our competition argument holds. To support the interpretation that competition from the HSR leads to 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 the nine cities linked to the Beijing–Guangzhou HSR line introduced on December 26, 2012. Moreover, the Beijing–Shanghai HSR and Beijing–Guangzhou HSR lines were both initiated by the central government in 2008; however, the latter finished construction 18 months after the opening of the Beijing–Shanghai HSR line[3]. Thus, the problem of non-random placement is much less a concern in

[3]Both the Beijing–Shanghai HSR and the Beijing–Guangzhou HSR lines are part of the "Four Vertical and Four Horizontal" medium- and long-term plan of the HSR network in China and construction work began in 2008. Since the length of the Beijing–Guangzhou HSR line is 2,298 km, which is 1.74 times that of

the comparison of the 11 treated cities with the nine control cities. 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, providing evidence of 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 treated flights' responses to the competition shock.

We also conduct several robustness checks to strengthen our estimation. For instance, we extend our sample period to September 2015 to include the introductions of another 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 that flights on short and medium routes (air distance within 1,200 km) are more responsive to competition from the HSR than flights on long routes (air distance exceeds 1,200 km). Moreover, the falsification tests create an artificial treatment group and an artificial treatment date, allowing us to 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 benefits of time saving for travelers who continue to take airplanes, which previous studies have not calculated or included. The benefits of time saving for air travelers on the affected one-way flights flying from Beijing to the 33 HSR cities between June 30, 2011 and September 30, 2015 is CNY 2.96 billion, excluding passengers who switch from airplanes to high-speed railways.

The remainder of the paper is organized as follows. Section 2 provides some background on the HSR network and airline delays in China and discusses the related literature. Section 3 describes the dataset. Section 4 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.

the Beijing–Shanghai HSR line (1,318 km), the construction of the Beijing–Guangzhou HSR line took longer, and the Beijing–Guangzhou HSR was put into use 18 months after the opening of the Beijing–Shanghai HSR line.

[4]Table B1 in the Appendix summarizes the opening dates of all these HSR lines. Many cities were connected to Beijing following the completion of some of these new HSR lines. For instance, the Beijing–Guangzhou HSR line was launched on December 26, 2012 and the Shanghai–Kunming HSR line was launched on September 14, 2014.

2 Background and Literature

2.1 Introduction of the HSR

After 20 years of development and expansion, China's high-speed railways, which are designed for speeds of 250 to 350 kph (155 to 217 mph), have become the largest and most extensively used HSR network in the world. Zhou et al. (2018) review the development of the HSR network over time. As of mid-2018, China's HSR network had expanded to 29 provinces, reaching approximately 27,000 km (17,000 miles) in total length and accounting for about two-thirds of the world's HSR tracks in commercial service. The medium-term plan[5] of the Chinese government is to expand the HSR network to 38,000 km (24,000 miles) by 2025. Based on a network plan of "eight vertical and eight horizontal," Beijing is regarded as the most important starting point of the vertical lines[6].

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

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

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

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

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

while air travelers spend only 62% of their total journey time on the plane, highlighting the efficiency of traveling by HSR. Since punctuality, connectivity, commute time, and cost efficiency have been shown to be the most important determinants for travelers' choice of transport mode, the new Beijing–Shanghai line imposes fierce competition on flights linking Beijing to other cities along the way.

2.2 Flight Delays

Many studies find 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 $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 report by the Civil Aviation Administration of China, air passenger traffic grew from 18.2 billion in 1987 to 837.8 billion in 2016[9]. According to this report, China has been the second largest airline market since 2005 and is expected to overtake the United States as the largest airline market by 2022[10].

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

Specifically, BCIA sent out 286,602 flights in 2017, and only 53.7% of them departed on time (i.e., within 15 minutes of their scheduled departure times). Moreover, departure delays

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

[9]See *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 flights departing within 15 minutes of their scheduled departure time to the total number of flights in a year.

averaged at around 48.5 minutes[13]. By comparison, China's most punctual airport, Xining Cao Jia Bao Airport, sent out 24,077 flights in 2017 and 78.2% departed on time; departure delays averaged at around 23.4 minutes. The world's most punctual airport, Osaka International Airport, sent out 74,914 flights in 2017 and 94.7% departed on time; departure delays averaged at around 13.1 minutes. Given the coexistence of BCIA's world-class capacity and notorious on-time performance, it is thus worthwhile studying the competition effect of HSR entry on the on-time performance of Beijing-departure flights.

2.3 Related Literature

This study adds to the literature that examines the causal effects of competition on quality and productivity. While consensus has been reached on the effects of competition on pricing behavior[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 the positive effects of competition on productivity, while Gal-Or (1983) suggests a negative relationship. Holmes and Schmitz Jr (2010) review 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 influences productivity must be identified. We contribute to this strand of the literature by analyzing the variation in competition from a clean source and by identifying an accurate mechanism for the improvement in airline service quality.

This study also complements the literature on airline competition. An extensive amount of empirical work has proven that competition in the airline industry improves the on-time performance of flights (Mazzeo, 2003; Rupp et al., 2006; Prince and Simon, 2009, 2015; Greenfield, 2014; Goolsbee and Syverson, 2008). To the best of our knowledge, we are the first researchers to study how service quality in the airline industry is affected by competition from HSR. Clear definitions of HSR competition and an airline's service quality (i.e., on-time performance) as well as the exogenous variations in HSR competition allow us to establish causal interpretations of the competition-on-time performance relation. 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 manage the airline industry and improve airline efficiency—even in the absence of HSR competition.

[13]This figure is calculated 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 that competition in the airline industry reduces airfares.

This study also contributes to yet another strand of the literature on HSR. With the rapid expansion of the HSR network globally, economists have paid a great deal of attention to the economic outcomes closely related to the introduction of an HSR. Shao et al. (2017) and Ahlfeldt and Feddersen (2017) exploit a DID model and find that the introduction of an HSR enhances economic development. However, some studies argue that such an introduction primarily benefits large cities as opposed to small counties (Zheng and Kahn, 2013; Qin, 2017). In addition, HSR has been found to positively influence intercity mobility (Chen, 2012; Tierney, 2012), market integration (Zheng and Kahn, 2013), population density, and employment (Levinson, 2012).

A number of recent studies have examined the impacts of HSR on the airline industry, most of which 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 competition between HSR and airlines varies by travel purpose. Yang and Zhang (2012) show that both airfares and HSR fares decrease with the weight of welfare in the HSR's objective function, while airfares decrease and HSR fares increase in response to a rise in airport access time. Fu et al. (2012) analyze whether China's airline industry can survive the growing expansion of the HSR network. In line with the competition effects of HSR on airlines revealed in France, the United Kingdom, Taiwan, Japan, and Korea (Park and Ha, 2006; Gleave, 2006; Behrens and Pels, 2012; Albalate et al., 2015), Fu et al. (2012) show that the entry of the HSR takes a large proportion of market share from airlines, particularly on short-to-medium routes linking metropolitan cities. For instance, in March 2010, all 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) find that competition between HSR lines and airlines is fiercer in medium-haul transport markets, where the travel distance is approximately 400 to 1,200 km (or a travel time of about four hours). Overall, the literature provides abundant evidence that HSR threatens the survival of airlines.

3 Data and Summary Statistics

3.1 Data

Using the on-time performance data provided by a leading data company that focuses on commercial aviation, this study examines the non-price responses of airlines to the entry of the HSR in China. The data company is a provider of comprehensive real-time global flight data to enterprises and individuals across the travel ecosystem. Specifically, we use data

on the on-time performance of all flights departing from Beijing to other domestic cities[15] between January 2009 and December 2012 in the baseline analysis.

In total, our dataset comprises details 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 services. We restrict our analysis to non-stop services because on-time performance is measured only for individual flights. To illustrate, we consider CA1515 departing from Beijing to Shanghai to be an example. Since we have only one departure airport, BCIA, in the data, the destination city (i.e., Shanghai) also refers to a route. China Air (CA) refers to an airline company. CA1515 refers to a flight.

The dataset includes most information on a flight such as flight number, scheduled departure and arrival time, actual departure and arrival time, time spent traveling from the gate to the runway (taxi-out time), time spent traveling to the gate after landing (taxi-in time), and time spent in the air (airtime).

Since the Beijing–Shanghai HSR line began operating on June 30, 2011, the sample period covers a sufficient time window to study the event of the HSR entry. In addition, because the Beijing–Shanghai HSR line is the first[16] and only Beijing-departure HSR operating during the sample period, we can conduct clean analyses of the effect of HSR competition on airline service quality. Table B1 in the Appendix summarizes the HSR destinations linked to Beijing along the different HSR lines. The opening of the Beijing–Shanghai HSR line on June 30, 2011 directly affected 26 destinations. Among these 26 destinations, 17[17] are located along the Beijing–Shanghai HSR line. While the other nine destinations[18] are not located along the line, they have also been linked directly to Beijing since June 30, 2011, when several already established HSR lines involving these destinations became connected to the Beijing–Shanghai HSR line at certain intersections. For instance, the Beijing–Hangzhou HSR became available on June 30, 2011 because the Beijing–Shanghai HSR line was connected to that line, which was introduced on October 26, 2010.

Flights link 113 destinations with Beijing. As shown in Figure 1, of these 113 destinations, 11[19] became reachable by the Beijing-departure HSR following the introduction of the Beijing–Shanghai HSR line. Therefore, flights departing from Beijing to these 11 destina-

[15]Some of these cities have no direct/indirect flights to Beijing.

[16]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.

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

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

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

tions are considered to be the treatment group because they are subject to the competition pressure imposed by the introduction of the Beijing–Shanghai HSR line and the remaining Beijing-departure flights serve as the control group. Figure A1 in the Appendix presents the monthly trends of four on-time performance measures for the treatment and control groups from January 2009 to December 2012.

[Figure 1 inserted here]

To conduct a general analysis that includes the introduction of other Beijing-departure HSR lines such as the Beijing–Guangzhou HSR line and Tianjin–Qinhuangdao HSR line, we extend our analysis by focusing on a longer sample period that ranges from January 2009 to September 2015. More specifically, 18 new HSR tracks operated between December 2012 and September 2015. In this period, the data are expanded to include more than 2.45 million flights and the number of treated destinations reached by Beijing-departure high-speed railways increases from 11 to 33. Figure 1 presents the geographic distribution of treatment and control destinations. Specifically, the railway and airport signs (including red, green, and blue ones) denote the 113 domestic destinations reached by Beijing-departure direct flights between January 2009 and December 2012. The blue railway signs represent the 11 destinations linked to the Beijing–Shanghai HSR line and comprise 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 the other Beijing-departure HSR lines were introduced after December 2012. Therefore, between January 2009 and December 2012, the destinations labeled with red and green railway signs in association with the destinations labeled with airport signs comprise 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 hourly data on weather conditions including temperature, rainfall, and visibility at the site of BCIA for our sample period from *Wunderground*[20].

3.2 Outcome Variables: Measures of On-time Performance

Similar to studies of 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 the HSR in terms of on-time performance. We employ different measures of on-time performance suggested by previous studies (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 Si-

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

mon (2015), we estimate weighted least squares (WLS) models using the number of flights on each airline route in each month as the weight in the respective cells. This enables us to produce the same estimates as those extracted from performing ordinary least squares on the disaggregated flight-level data.

We employ three measures of on-time performance for both the arrival and the 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 the 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 proportion 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*.

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

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

[Figure 2 inserted here]

Table 1 reports the summary statistics of the 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 (865,967 individual flights) and Panel B corresponding to the airline-route-month-level statistics (12,499 airline-route-month observations). For both treated and control flights, the average flight delays in minutes over the departure period, including *ArrDelay in minutes*, *DepDelay in minutes*, *ATT*, and *ETT*, increase by one to four minutes in the post-HSR period. However, the increments of delays for treated flights are lower than those for control flights.

[Table 1 inserted here]

4 Empirical Approach

We employ two complementary approaches to investigate the empirical relationship between competition and an airline's service quality. Specifically, we first assess the correlation between 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 the HSR on an airline's on-time performance.

4.1 Relationship between HSR Competition and Flight Delays

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

Figure 3 presents the unconditional correlations of flight delays with competition from HSR lines in four months: July 2011, January 2012, June 2012, and May 2013. The y-axes indicate the two measures of delays (*delayed minutes* and *delayed rate*) for arrival flights (top two graphs) and departure flights (bottom two graphs) at the month level[21] and the x-axes denote the number of scheduled HSR trains per day in a month. The negative relationships shown in all four graphs in Figure 3 indicate that the larger the number of scheduled HSR trains on a route, the lower is the number of minutes a flight on the route is

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

delayed, suggesting that competition from 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 April 2009, December 2010, July 2011, January 2012, June 2012, and May 2013. The observations in the first two columns are fewer than those in the last two columns because Columns (1) and (2) only include flights on the HSR lines in July 2011, January 2012, June 2012, and May 2013, while Columns (3) and (4) include flights on all non-HSR lines in April 2009, December 2010, July 2011, January 2012, June 2012, and May 2013. The coefficients of the number of HSR trains are negative and significant in Columns (1) and (2), supporting the competition argument in Figure 3. Specifically, a one-unit increase in the number of HSR trains is associated with a 0.79-minute (0.83-minute) decrease in arrival (departure) delays. The results in Columns (3) and (4) show that the numbers of non-HSR trains are negative and not statistically significant, 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 improvements in flight operational efficiency. However, the results might be subject to omitted variable bias, such as unobserved pressure from the government, which leads to more intense competition and fewer flight delays. To address these endogeneity concerns, we extend our analysis of the entry of the HSR to flight routes along the Beijing–Shanghai HSR line in the following section. Specifically, we study the responses of the different measures of flight delays to the exogenous shock of the HSR entry.

4.2 Flight Delays and HSR Entry

To examine the causal effects of HSR entry on the service quality of the affected flights, we employ a DID approach and apply it to the individual flight-level and airline-route-month-level estimations. This approach allows us to alleviate the endogeneity concerns related to the fact that competition and service quality within an industry are not only potentially mutually dependent, but also potentially simultaneously affected by local attributes, such as preferential treatment and institutional quality.

The basic specification of 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 that takes the value 1 after June 30, 2011 and 0 otherwise. β is the parameter of interest to be estimated, which captures the difference in the average post-HSR delays of a treated flight relative to the post-HSR delays of a control flight. μ_i refers to the flight fixed effect (flight number), capturing unobserved factors that may affect flight delays at the flight level, at the airline company level, and at the destination (route) level. For example, CA1831 departs from Beijing to Shanghai. Therefore, controlling for the flight fixed effect (i.e., CA1831) actually absorbs the unobserved characteristics across flights (i.e., CA1831), across airline companies (i.e., CA), and across destinations (i.e., Shanghai). The term δ_{hour} represents the hourly fixed effects, which account for any hourly variations that may affect flight delays, such as the hourly density of departure flights. We also include the date fixed effects ζ_t to eliminate any seasonal and national trends. The standard errors are clustered at the destination level to capture the potential serial correlations in the residual error terms.

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 the average delay for airline company j departing from Beijing to destination d in month m. In the aggregate-level regressions, we control for airline fixed effects, destination (route) fixed effects, and year-month fixed effects. We estimate WLS models for the aggregate-level data by weighting each observation by the number of flights in each cell.

Initially, we examine the introduction of the first Beijing-departure HSR line, the Beijing–Shanghai HSR line, and restrict the sample period to January 1, 2009 to December 26, 2012. Generalizing our conclusions, we also extend the analysis by examining a longer period, namely January 1, 2009 to September 30, 2015. In this lengthened sample period, more Beijing-departure high-speed railways are covered.

Nevertheless, the Chinese government's decision to introduce high-speed railways was dependent on several factors including economic (Ahlfeldt and Feddersen, 2017) and strategic considerations (Shao et al., 2017) as well as lobbying (Albalate and Fageda, 2016). This is not a concern provided the factors are independent of individual flight-level delays. However,

if any factors that drive the introduction of the HSR and individual flight-level delays are simultaneously omitted, then any correlation between them could be spurious. 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 in many cities in China, especially those located in metropolitan areas, improving the on-time performance of the airline industry has become a priority for local governments. A more efficient airport or airline industry enhances the city's domestic and international reputation and helps attract investors and tourists. At the same time, the introduction of HSR lines may be necessary (e.g., because of 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 the airline industry and establish an HSR network.

In this case, finding a negative treatment effect would be a spurious outcome of an omitted variable in destinations. Fortunately, because the treated group is uniquely defined by two locations, Beijing and one of the destinations on the Beijing–Shanghai HSR line, we can control for such route (destination) shocks, extracting the effects of opening the 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 changed after June 30, 2011, then an increase in the on-time performance of Beijing–Shanghai flights might not be due to the newly introduced HSR line between Beijing and Shanghai, but rather a contemporaneous destination shock (i.e., shrinking demand). In principle, we could control for such destination (route) shocks by including a full set of destination (route) fixed effects interacted with the year-month fixed effects.

At the route level, another endogeneity concern is related to air traffic control in the post-HSR period. To elaborate on the impacts of air traffic control (especially for military purposes[22]), the air traffic control data are divided into three sources or categories: (1) Beijing Airport, (2) treated routes, and (3) control routes. The first two categories do not affect our interpretation of β in the equations. On the one hand, air traffic control at Beijing Airport should affect the treated and control flights in the same way, which suggests that

[22]As reported by Thomson Reuters, China is set to overtake the United States as the world's largest aviation market by 2024; however, airlines and travelers 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.

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

4.2.2 Airline-level (Firm-level) Shocks

We can also control for airline-level (firm-level) shocks. For instance, if the on-time performance of flights on CA routes, which are not along the Beijing–Shanghai HSR line, also increase (or decrease) after June 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-year-month controls above, we account for airline-level shocks by including the airline-year-month fixed effects.

4.2.3 Flight-level (Individual Flight-level) Shocks

In addition to the route-level and airline-level shocks, shocks specific to a single flight might affect on-time performance, which could in turn contaminate our estimations. For instance, if the ID number of a flight was deleted or changed during our sample period (e.g., flight CA0000 (Beijing–Shanghai) changed its identification to CA0123 (Beijing–Shanghai)), then a comparison of the flight delays before and after the introduction of the HSR could be biased, as we would not be focusing on the same flight before and after the event. Because such shocks do not affect other flights between the same destinations, they cannot be captured by the inclusion of the route-year-month fixed effects. Similarly, since such shocks do not affect other flights run by the same airline company, they cannot be absorbed by including the airline-year-month fixed effects.

One efficient way in which to deal with such possible bias is to implement the regressions using airline-route-month-level data. In particular, we aggregate our individual flight-level data at the airline-route-month level. For instance, although flight CA0000 (Beijing–Shanghai) changed its identification to CA0123 (Beijing–Shanghai), we can still examine the variations at the airline-route-month (i.e., CA-Beijing–Shanghai-month) level before and after the entry of the HSR. 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 on a monthly basis. The aggregation can also be considered to be a way in which to eliminate the effect of outliers.

5 Empirical Results

5.1 Core Results

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

[Table 3 inserted here]

Table 3 presents the main results, where Panels A, B, and C correspond to the estimations without route/airline shocks controlled for, with route shocks controlled for, and with airline shocks controlled for, respectively. In each panel, we employ three measures of arrival delays: *ArrDelay in minutes* (ADM), *ArrDelay 15 minutes* (ADD15), and *ArrDelay 30 minutes* (ADD30). The hour fixed effects, date fixed effects, and 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 finding 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 treated flights are less likely to arrive at least 15 (or 30) minutes late in the post-HSR period relative to non-treated flights. In particular, the treatment effect on the ADD15 measure is estimated to be -0.018, which is smaller than that of the ADD30 measure (-0.025). The data suggest that HSR competition has a greater effect on flights with worse on-time performance.

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 the route-year-month fixed effects) and airline level (by including the airline-year-month fixed effects). Sections 4.2.1 and 4.2.2 describe the route- and airline-year-month fixed effects. As shown, the coefficients of the interaction terms remain negative and statistically significant and the magnitudes of the coefficients change little. Overall, the results in Panels B and C indicate that route shocks and airline shocks do not explain away the HSR competition effects on airline quality.

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

WLS models by weighting each observation by the number of flights in each cell. The airline fixed effects, route fixed effects, and year-month fixed effects are included in all specifications. The delayed minutes in Column (1) denote the arrival-delayed minutes averaged in the airline-route-month cells. The *delayed rate15* and *delayed rate30* values in Columns (2) and (3) represent the probability of flights arriving at least 15 and 30 minutes late, respectively, in the airline-route-month cells. The coefficients of the treatment are consistently negative and significant in all columns, which implies 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 treated flights arriving at least 15 (30) minutes late is 2.4 (2.8) percentage points lower than that of non-treated flights in the post-HSR period. This finding suggests that our baseline results are robust to 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 the *scheduled* arrival and *actual* arrival. 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 a prolonged scheduled duration instead of actual improved quality. In addition, 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 in which to measure the flight delay. Therefore, we construct two alternative measures of delay: *TravelTime* and *Excessive TravelTime* (see more details in Section 3.2). The tests are expanded below.

5.2.1 Scheduled Flight Duration

Panel A in Table 5 reports the results using the *scheduled duration* as the dependent variable. We find that the coefficients of the interaction terms are not statistically significant in both the individual flight-level and aggregate-level regressions. These non-significant coefficients imply that the airlines of 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 to replicate the estimations. Panels B and C in Table 5 report the results. Consistent with the results in Tables 3 and 4, the estimates of the interaction terms are negative and statistically significant. The magnitudes are larger than those in the estimations using *ArrDelay in minutes* as the dependent variable, suggesting that treated flights experience a greater reduction in *TravelTime* and *Excessive TravelTime* than non-treated flights in the post-HSR period. These results are consistent with the findings of Prince and Simon (2009) and Prince and Simon (2015), which show that *TravelTime* and *ETT* are more responsive to competition than *ArrDelay in minutes*. The results in Table 5 reject the hypothesis that extreme weather conditions or occasional airport congestion lead to the change in on-time performance.

5.3 The Source of Improved Quality

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

5.3.1 Actual Duration

We first examine the competition effect of the HSR entry on the actual duration in both the individual- and the aggregate-level regressions. As shown in Panel A of Table 6, the coefficients of the interaction terms are not significant. These 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 finding suggests that the actual duration is not the source of a reduction in the arrival delays of treated flights. We then divide the actual duration into *taxi-out time*, *airtime*, and *taxi-in time* and use these as the dependent variables. As shown in Table B2 in the Appendix, 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 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 the 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 the arrival airports. Airtime usually depends on traffic congestion, wind direction, and 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 reflects improvements in quality, which subsequently reduces the departure delay.

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

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

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

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

First, the entry of the HSR 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 quality. Second, an airline 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 the departure delay would be caused by the cancellations of flights with poor on-time performance rather than by an improvement in quality. Third, airlines, especially hub airlines, could reschedule their flights and allocate flights to less congested time slots (i.e., night-time) (Mayer and Sinai, 2003), 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 delays results from rescheduling 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 next expand the examinations of these four alternative explanations.

5.4 Alternative Explanations

5.4.1 Holiday Analysis

To assess whether a decrease in air travelers leads to a decrease in the departure delay, we restrict our sample to include observations only around the most important holidays. Specifically, we extract observations seven days before and after the Spring Festival, three days before and after the Mid-autumn day, and three days before and after the National Day. In China, the Spring Festival, Mid-Autumn Day, and National Day are considered to be the three most important holidays and people typically take a vacation to celebrate. During the travel peak, all modes of transportation, including airplanes, run at full capacity. Thus, the number of travelers taking flights around the holidays should not decrease after the entry of the HSR. If the decrease in the departure delay is due to the entry of the HSR (rather than a decrease in the number of air travelers), then we should observe a significantly negative estimate of the treatment dummy in the holiday (subsample) analysis. The significantly negative coefficients of the treatment dummy in Table 7 verify this prediction, indicating that the 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 above, we first examine the variation in supply. We employ the number of flights at the flight-route-month, airline-route-month, and route-month levels 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 also consistent with the findings of Fu et al. (2012), who show that the affected flights were canceled permanently after the entry of the HSR.

[Table 8 inserted here]

Since the on-time performance of canceled flights may be worse than that of continuing flights, improvements in average on-time performance after the introduction of the HSR could be due to the cancellation of flights with poor on-time performance. To determine if this is the case, we re-estimate the individual and aggregate models using only continuing flights. If the reduction in delays 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 the HSR. Table 9 reports the results, with Panel A corresponding to the individual-level regressions and Panel B corresponding to the aggregate-level regressions. As shown, the introduction of the HSR is found to be statistically significant in reducing arrival delays, the actual travel time, the excessive travel time, and departure delays, but insignificant in affecting the 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 Rescheduling

Airlines may also improve their on-time performance by rescheduling flights and allocating flights to time slots less impacted by air traffic congestion. Figure A3 in the Appendix plots the average scheduled flights at 30-minute intervals on the day before and after the introduction of the Beijing–Shanghai HSR line between January 2009 and December 2012. While the patterns in the figure are similar, the number of flights (see the 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. Figure A4 in the Appendix plots the traffic volume and average departure-delayed minutes in each time slot before the introduction of the Beijing–Shanghai HSR line, showing that the departure flights scheduled for the 1am, 6am, 7am, 9am, 10am and 10–11pm slots have better on-time performance. These time slots can thus be considered to be better in terms of the on-time performance of departures. To assess whether treated airlines allocate 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 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 of the treatment dummies when estimating Equations (1) and (2). The results in Table 10 show that the estimated coefficients of $Treatment * After$ are neither positive nor statistically significant, suggesting that the rescheduling hypothesis does not hold.

[Table 10 inserted here]

5.4.4 Connecting Flights

A further competing explanation for the improved quality is that the flights in the control group in the post-HSR period experience more delays created by the delays of earlier flights (also called connecting flights). Therefore, the increased delays of flights in the control group in the post-HSR period may also lead to negative estimates of β in the baseline tables. To address this issue, we focus on a subsample consisting only of flights departing in the early morning (6am to 9am). Flights departing in the morning are less likely to be connecting flights. The results in Table 11 show that 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 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 the local economy, industry distribution, and geographic characteristics, the estimation results discussed above are subject to endogeneity bias. Many of the destinations in the control group, such as Yulin (a third-tier city), are not comparable to HSR destinations such as Shanghai (a first-tier city); 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 nine destinations[23] along the Beijing–Guangzhou HSR line. A public report[24] (indicated by the black railway signs in Figure 1) published by the central

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

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

government details that the Beijing–Shanghai and Beijing–Guangzhou HSR lines are part of the "Four Vertical and Four Horizontal" medium- and 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 18 months after the opening of the Beijing–Shanghai line. As shown in Figure 1 and Table B4 in the Appendix, 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 the 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 with the nine 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 between January 2009 and December 2012. Figure A2 in the Appendix 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). Table 12 reports the estimation results. 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 ordinary least squares estimation suggests that the entry of the HSR in June 2011 significantly improved the on-time performance of flights on the affected route. A prerequisite for the validity of the DID design is that the pre-trend of the outcome variables between the 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 treated flights.

Specifically, we add a new interaction term, $\beta_0 \cdot Treatment \cdot Before$, into 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 with 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 of $Treatment \cdot After$ capture the difference in the response of on-time performance after the HSR introduction compared with the first 12 benchmark months in our sample period. The validity of our DID research design requires β_0 to be statistically and economically indistin-

guishable from zero.

Table 13 shows the estimation results for the different measures of on-time performance. The coefficients of the $Treatment \cdot After$ dummy are negative and statistically significant for all the measures of on-time performance, consistent with the results in previous tables. However, the coefficient estimates of the pre-treatment period variable $Treatment \cdot Before$ are both economically and statistically non-significant. These results suggest that before the entry of the Beijing–Shanghai HSR line, there were no differences in the change patterns of on-time performance between treated and non-treated flights. This result provides strong evidence 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 response of treated flights 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 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, $\ldots$, and six quarters after the introduction of the Beijing–Shanghai HSR line, respectively. Similarly, coefficients $\beta_{-1}, \ldots, \beta_{-6}$ capture the difference in trends in on-time performance change between the treatment and control groups in each of the six pre-treatment quarters.

We find that the impact of competition from the Beijing–Shanghai HSR line on the on-time performance of flights persists after its 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. These four graphs indicate that treated flights start responding to competition from the Beijing–Shanghai HSR line immediately after its introduction; the response in on-time performance thus seems to persist.

[Figure 4 inserted here]

6 Additional Tests

6.1 Air Traffic Control on Control Routes

Air traffic control aims to move aircraft safely and efficiently through the airspace system. If the government or military tightens air traffic control on non-treated routes in the post-HSR period, our estimate of the treatment effect of HSR could be overstated. To address this issue, we use an alternative group consisting of routes less likely to be affected by the Chinese authorities. This alternative group comprises international air routes. Therefore, international flights departing from Beijing serve as a new control group in the DID estimations. Since international flights take triple the journey time on average relative to domestic flights, the arrival and travel times are dependent on many external unpredictable factors. Table B5 in the Appendix reports the results. The coefficients of the interaction term remain significantly negative and the magnitudes are greater than those in the baseline analysis, suggesting that air traffic control on control routes inducing an overestimation is not a concern.

6.2 A General Study

For a robustness check, we expand the study to a more general case by focusing on a longer sample period from January 2009 to September 2015. The new sample period contains 19 introductions of HSR lines (see Table B1 in the Appendix for more details), such as the opening of the Beijing–Shanghai HSR line on June 30, 2011, the Beijing–Guangzhou HSR line on December 26, 2012, and the Tianjin–Qinhuangdao line on December 31, 2013. In the general study, the number of treated destinations (routes) increased from 11 to 33. Table 14 reports the results of regressing the different measures of on-time performance against the treatment dummy in the expanded sample. To be concise, we only report the regression results for 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 and non-hub airlines as well as on short-to-medium-haul and long-haul flights.

Hub airlines can absorb greater marginal delay costs than their non-hub peers because they gain network benefits from additional flights (Mayer and Sinai, 2003). Therefore, given

that hub and non-hub airlines may have different incentives to improve their quality, they may respond differently to the entry of the HSR. The dominant hub airline of BCIA is CA. According to the Civil Aviation Administration, China Southern Airlines, China Eastern Airlines, Hainan Airlines, and Beijing Capital Airlines are also considered to be hub airlines of BCIA.

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

According to (Fu et al., 2012; Yang and Zhang, 2012), HSR lines impose the most fierce competition for air routes within 1,200 km. Therefore, we use 1,200 km[25] as a cutoff to categorize flights into short-to-medium-haul and long-haul routes. Panel B of Table 15 presents the estimates of the impact of the HSR entry on the on-time performance of short-to-medium-haul and long-haul routes. STM is a dummy equal to 1 if the distance between Beijing and the destination is below 1,200 km and 0 otherwise. The estimated coefficients of $Treatment * After * STM$ are significantly negative for three out of the four measures of on-time performance, suggesting that short-to-medium-haul flights are more responsive to competition from 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 in which we create an artificial treatment group consisting of nine destinations linked to the Beijing–Guangzhou HSR line after December 2012. As discussed above, although these nine cities enter the HSR network after December 2012, none of them in the artificial treatment group was linked to the Beijing–Shanghai HSR line between January 2009 and December 2012. This test addresses whether the difference in the original DID regressions reflects HSR competition or just a more general

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

effect related to the characteristics of HSR destinations.

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

Tables B6 and B7 in the Appendix report the regression results on the placebo treatment group and placebo treatment date, respectively. In both placebo tests, we find that the estimated coefficients of the interaction terms are not statistically different from zero. This finding concurs with the results above because of the difference in the HSR introduction across destinations as opposed to the characteristics of the HSR destinations or airline industry cycle or resulting from broader HSR network planning.

7 Discussion

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

Home to the largest HSR network (60% of the world's total in 2016), China manages HSR lines that cover 24,000 km (15,000 miles). The rapid rate of expansion of the HSR network presents an enormous challenge for Chinese airlines in terms of implementing effective planning and formulating response strategies to deal with potential customer churn. Examining the impacts of China's HSR on the non-price characteristics of the airline industry could reveal valuable policy implications for other countries considering or developing an HSR network.

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

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

where $Wage$ denotes the average yearly salary. According to the data released by the National Bureau of Statistics[26], the average yearly salary in Beijing in 2012 was CNY 62,676. The denominator, 2000, represents the total number of efficient working hours in a year[27].

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

[27]Suppose people work 8 hours per day, 5 days per week, and 52 weeks per year. After excluding 10 days

α_i is a parameter that measures the relative time value across passenger types. This is a function of the transport mode choice and purpose of travel. Following Yang and Zhang (2012), we divide air passengers into business passengers (i=1) and leisure passengers (i=2). The time value of business passengers is set to be three times as large as that of leisure passengers. We then set α_1=9 and α_2=3 according to the designs of Li et al. (2007) and Yang and Zhang (2012). Therefore, the hourly flight delay costs for business and leisure passengers are CNY 282 and CNY 94, respectively.

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

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

where N denotes the total seat count, β denotes the occupation rate, and θ_i denotes the share of passenger type i. According to the Civil Aviation Administration[28], 46% of all airline passengers travel on business and 54% travel on leisure. That is, θ_1=0.46 and θ_2=0.54. Suppose that each flight has 200 seats on average and an occupancy rate of 80%. Then, the cost C for all passengers of an aircraft due to an additional minute of delay is 481.28.

Given that our estimated reduction in the arrival delay for all treated flights before September 2015 is 3.85 minutes (as shown in Table 14), a simple estimate of the per flight time saving from the reduced arrival delay in the post-HSR period is equivalent to CNY 3.85*481.28=1,852.93. Notably, this is an underestimation of the total benefits for treated air travelers because it does not take into account the decrease in airfare caused by the entry of the HSR. To provide a more intuitive image of the benefits of time saving for air travelers on the affected routes, we use all flights along the HSR routes in the post-HSR period for illustration purposes. In our data, 796,191 treated flights fly from Beijing to the 33 HSR cities between June 30, 2011 and September 30, 2015. The total gain of time saving for air travelers on the affected routes is thus calculated as CNY 796,191*1,852.93*2 =2.96 billion.

7.2 Other Consequences of Competition

This study does not estimate the effects of the entry of the HSR on airfares or airline revenues since flight-level real-time price data and airline route-level revenue data are unavailable. 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 well-documented issue of flight delays in China, more attention could be given to the effects on on-time performance in future work.

of statutory public holiday, total efficient working hours are 8*5*52-8*10=2000.

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

7.3 Policy Implications

In this study, we find that the introduction of the HSR imposed pressure on 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 intuitive 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 study, we exploit the entry of the HSR into various destinations to examine the quality response of air transportation services using a dataset of all the flights departing from Beijing. This dataset is unique in that it provides details on flight timeliness that can be used to measure the service quality of airlines. Moreover, the disaggregated microdata enable us to examine the variation in flight timeliness across airlines and destinations.

We use a DID strategy to establish the causal impact of competition on quality and examine the possibility of endogeneity and omitted shocks at both the route and the 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 flights departing from Beijing to destinations linked to this HSR line with flights departing from Beijing to other destinations before and after the introduction of the Beijing–Shanghai HSR line. After

controlling for the route and airline fixed effects, the specific timing of the 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 January 2009 and December 2012, during which the Beijing–Shanghai HSR was 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 no differences in on-time performance between treated and non-treated flights existed before the opening of HSR lines. The sample selection issue is addressed by conducting a more valid comparison between the 11 treated destinations and nine 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. These effects are persistent and robust to the inclusion of various fixed effects, suggesting that improvements in the operational efficiency of air transportation services are not attributable to changes in airline-level shocks, local market shocks, or adjustments in supply that may have followed the entry of the HSR lines. Decomposing the actual travel time and replicating the estimations, we find that the decrease in the departure delay is the source of the improvement in on-time performance. Our HSR competition argument is clear of four alternative explanations, including the deletion of inferior flights, a supply decrease, rescheduling, and delays to earlier flights. The heterogeneity tests show that non-hub airlines and airlines on routes within 1,200 km are more responsive to HSR competition. The results of our falsification tests support our HSR competition argument, as those with either an artificial treatment group or an artificial treatment date show no statistical significance. Lastly, we provide a back-of-the-envelope analysis and reveal that the total gain for air travelers on the affected one-way flights flying from Beijing to the 33 HSR cities between June 30, 2011 and September 30, 2015 is CNY 2.96 billion.

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

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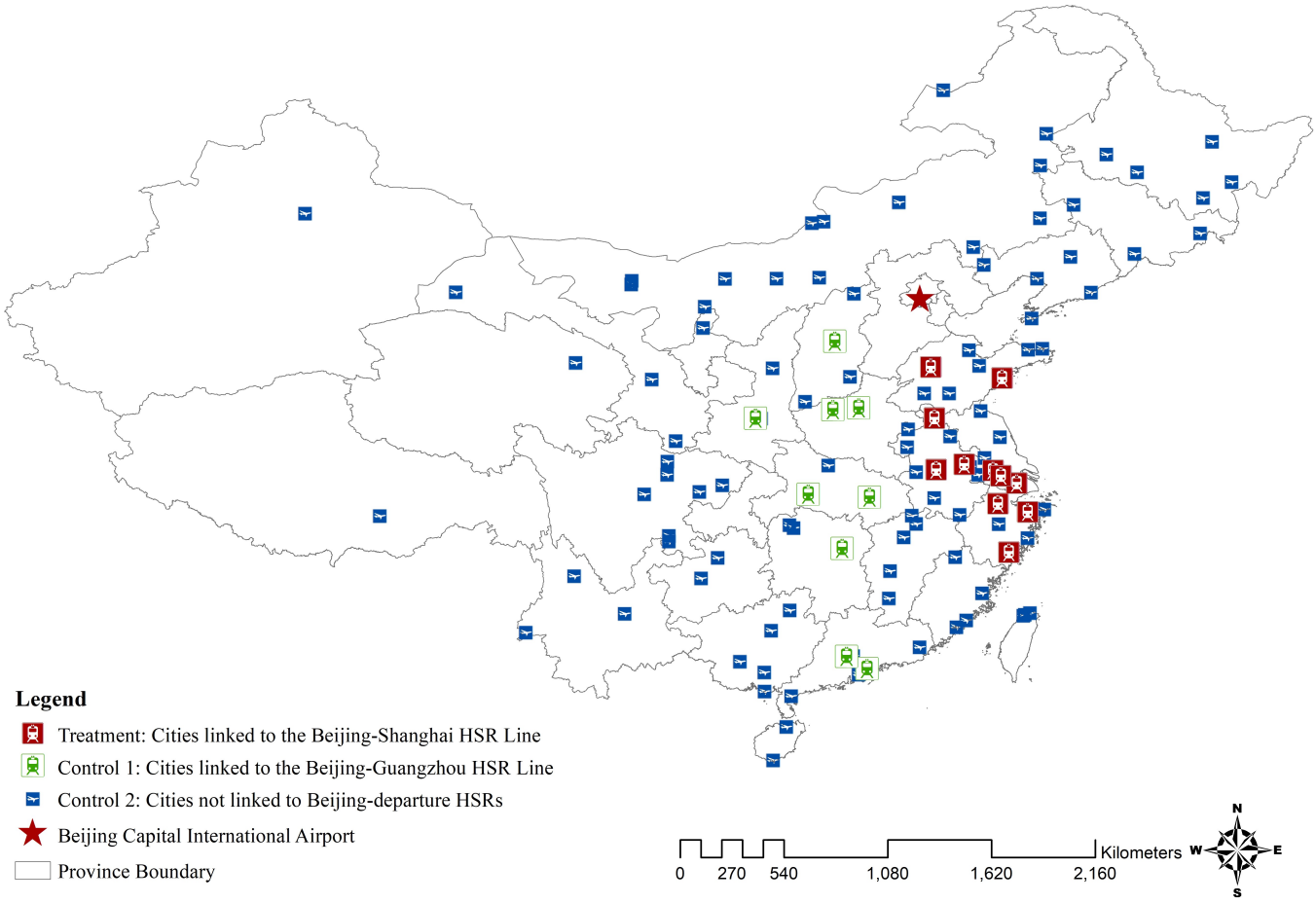
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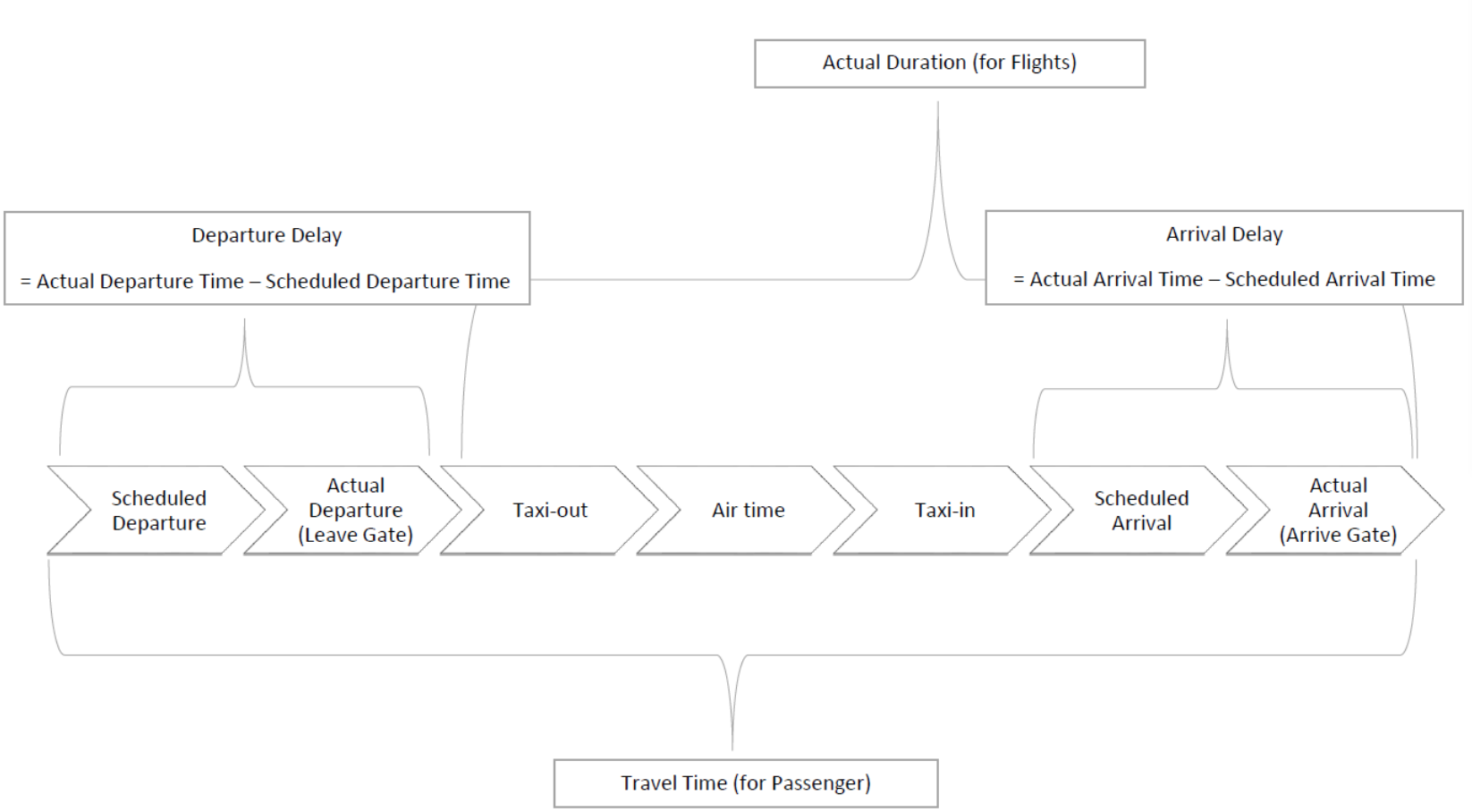
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Figure 1: Geographic Distribution of Sample Cities in September 2015
and HSR/chinarailmap12.jpg



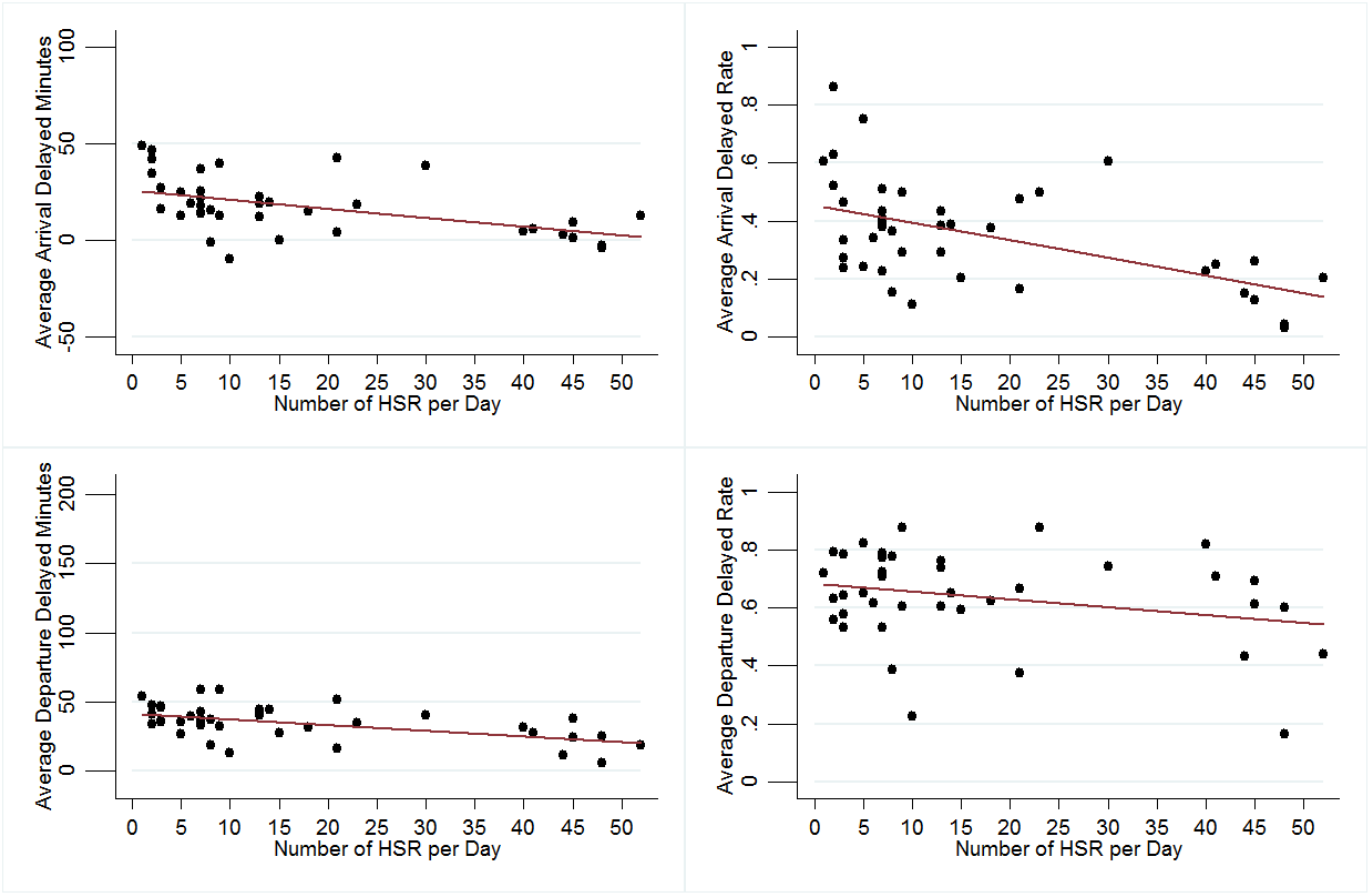
Notes: This figure presents the geographic distribution of the sample destinations in September 2015. The red railway signs denote the 11 treated destinations linked to the Beijing–Shanghai HSR line introduced on June 30, 2011. The green railway signs denote the nine destinations linked to the Beijing–Guangzhou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

Figure 2: Flowchart for Flight Delays



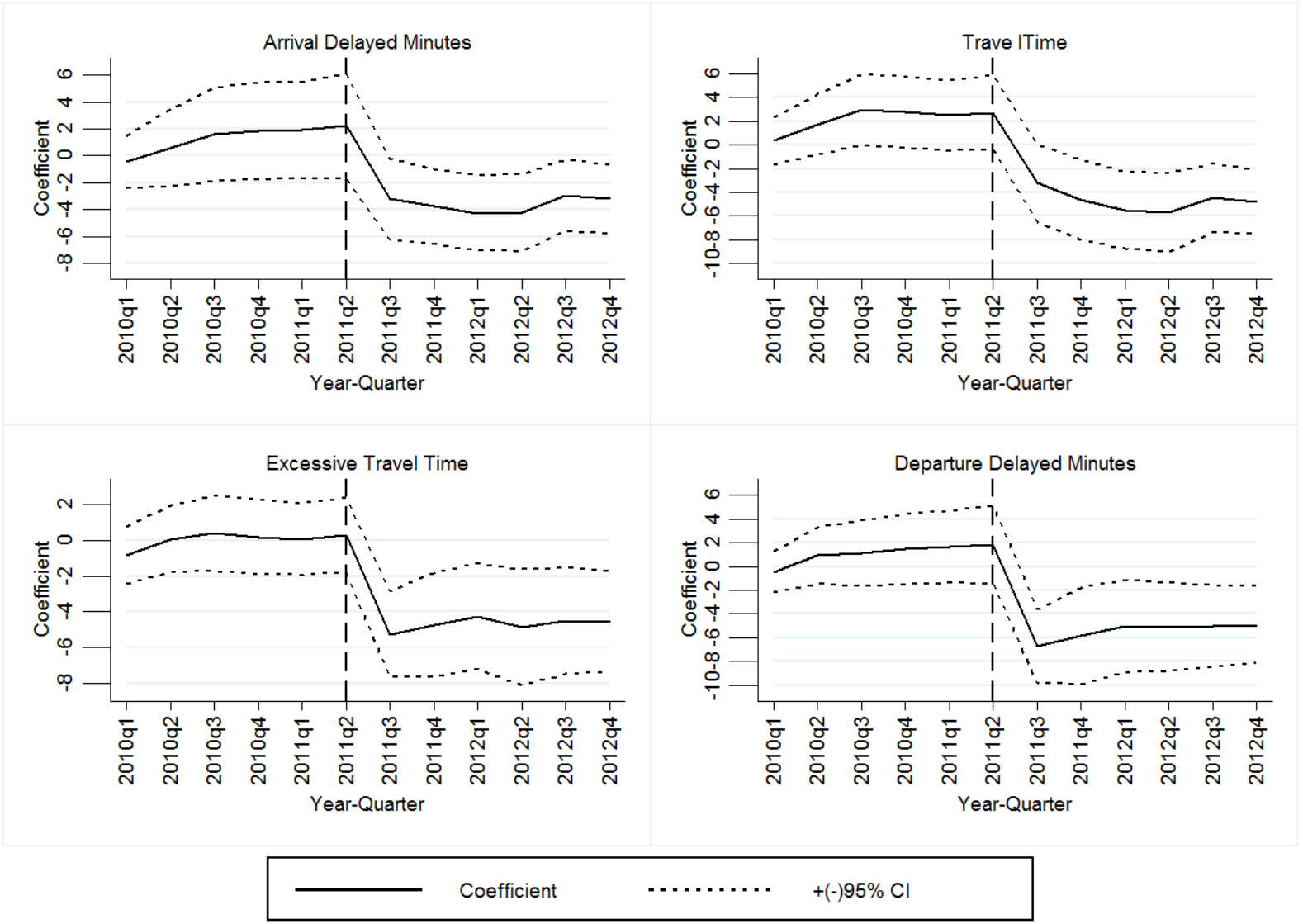
Notes: The flowchart illustrates the components of the flight departure and arrival delays. *TravelTime* (denoted as ATT in the tables) captures the time difference between the *scheduled departure time* and *actual arrival time*. The *departure delay* is calculated as the time spent before leaving the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

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



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

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



Notes: This figure plots the dynamic responses of the four on-time performance measures to the introduction of the Beijing–Shanghai HSR line. The coefficients are obtained from estimating Equation (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 the variables used in the study. The sample includes all Beijing-departure flights between January 1, 2009 and December 26, 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 HSR lines or number of non-HSR lines. Columns (1) and (2) only include flights departing from Beijing to destinations linked to the HSR line in July 2011, January 2012, June 2012, and May 2013. Columns (3) and (4) only include flights departing from Beijing to destinations linked to an ordinary Beijing-departure train in April 2009, December 2010, July 2011, January 2012, June 2012, and May 2013. The hour, date, and flight fixed effects are included in all specifications. Standard errors clustered by destinations are reported in parentheses. We use ***, **, and * to denote significance at the 1%, 5%, and 10% levels, respectively.

Table 3: Effects of the HSR on Arrival Delays at the 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-Year-Month FE	No	No	No	No	No	No	Yes	Yes	Yes
Route-Year-Month FE	No	No	No	Yes	Yes	Yes	No	No	No

Notes: This table reports the results of estimating Equation (1). ADM is 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. The sample period is from January 2009 to December 2012. The hour, date, and flight fixed effects are included in all specifications. The route dummy interacted with the year-month dummy is included in Panel B (Columns (4)–(6)) and the airline dummy interacted with the year-month dummy is 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% levels, respectively.

Table 4: Effects of the HSR on Arrival Delays at the 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
Year-Month FE	Yes	Yes	Yes
Airline FE	Yes	Yes	Yes
Route FE	Yes	Yes	Yes

Notes: This table reports the results of estimating the WLS models based on Equation (2), weighting each observation by the number of flights in each cell. The delayed minutes in Column (1) denote arrival-delayed minutes averaged by airline-route-month. Delayed rate15 and delayed rate30 in Columns (2) and (3) represent the proportion of flights arriving at least 15 and 30 minutes late, respectively, in the airline-route-month cells. The sample period is from January 2009 to December 2012. The year-month, airline, and route fixed effects are included in all specifications. Standard errors clustered by destinations are reported in parentheses. We use ***, **, and * to denote significance at the 1%, 5%, and 10% levels, respectively.

Table 5: Effects of the 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
Year-Month 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 the HSR introduction on scheduled duration, travel time, and excessive travel time. The individual- and aggregate-level regressions are presented in each panel. The sample period is from January 2009 to December 2012. The hour, date, and flight fixed effects are included in the individual regressions. The year-month, airline, and route fixed effects are included in the aggregate regressions. Standard errors clustered by destinations are reported in parentheses. We use ***, **, and * to denote significance at the 1%, 5%, and 10% levels, respectively.

Table 6: Effects of the HSR Introduction on the 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
Year-Month 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 the HSR introduction on the actual duration and departure delay. The individual- and aggregate-level regressions are presented in each panel. The sample period is from January 2009 to December 2012. The hour, date, and flight fixed effects are included in the individual regressions. The year-month, airline, and route fixed effects are included in the aggregate regressions. The 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% levels, 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 that includes observations seven days before/after the Spring Festival, three days before/after the Mid-Autumn Day, and three days before/after the National Day. ADM is short for Arrival Delayed in Minutes and DDM is short for Departure Delayed in Minutes. The sample period is from January 2009 to December 2012. The hour, date, and flight fixed effects are included in all specifications. Standard errors clustered by destinations are reported in parentheses. We use ***, **, and * to denote significance at the 1%, 5%, and 10% levels, respectively.

Table 8: 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
Year-Month FE	Yes	Yes	Yes
Flight FE	Yes	No	No
Airline FE	No	Yes	No
Route FE	No	Yes	Yes

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

Table 9: Analysis on Survival Flights

Panel A. Regressions of the 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 of the 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
Year-Month 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 that existed both before and after the introduction of the Beijing–Shanghai HSR line. Panel A reports the results of estimating the effects of the HSR introduction on the arrival delay, actual travel time, excessive travel time, actual duration, and departure delay at the individual flight level. Panel B focuses on the estimation results at the aggregate level. The hour, date, and flight fixed effects are included in all specifications in Panel A. The year-month, airline, and route fixed effects are included in all specifications in Panel B. Standard errors clustered by destinations are reported in parentheses. We use ***, **, and * to denote significance at the 1%, 5%, and 10% levels, respectively.

Table 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
Year-Month FE	No	Yes
Flight FE	Yes	No
Airline FE	No	Yes
Route FE	No	Yes

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

Table 11: Regressions of 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 subsample consisting of flights departing in the early morning (6am to 9am) only. The hour, date and flight fixed effects are included all columns. Standard errors clustered by destinations are reported in parentheses. We use ***, **, and * to denote significance at the 1%, 5%, and 10% levels, respectively.

Table 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
Year-Month 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 the subsample. The sample period is from January 2009 to December 2012. The treatment group includes flights departing from Beijing to the 11 destinations linked to the Beijing–Shanghai HSR line. The control group includes flights departing from Beijing to the nine destinations linked to the Beijing–Guangzhou HSR line after December 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 excessive travel time. The year-month, airline, and route fixed effects are included in all specifications. Standard errors clustered by destinations are reported in parentheses. We use ***, **, and * to denote significance at the 1%, 5%, and 10% levels, respectively.

Table 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
Year-Month FE	Yes	Yes	Yes	Yes
Airline FE	Yes	Yes	Yes	Yes
Route FE	Yes	Yes	Yes	Yes

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

Table 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
Year-Month 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. The sample period is from January 2009 to September 2015. The number of treated destinations increased from 11 to 33 in September 2015. The estimations are conducted at the airline-route-month level. 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 excessive travel time. The year-month, airline, and route fixed effects are included in all specifications. Standard errors clustered by destinations are reported in parentheses. We use ***, **, and * to denote significance at the 1%, 5%, and 10% levels, respectively.

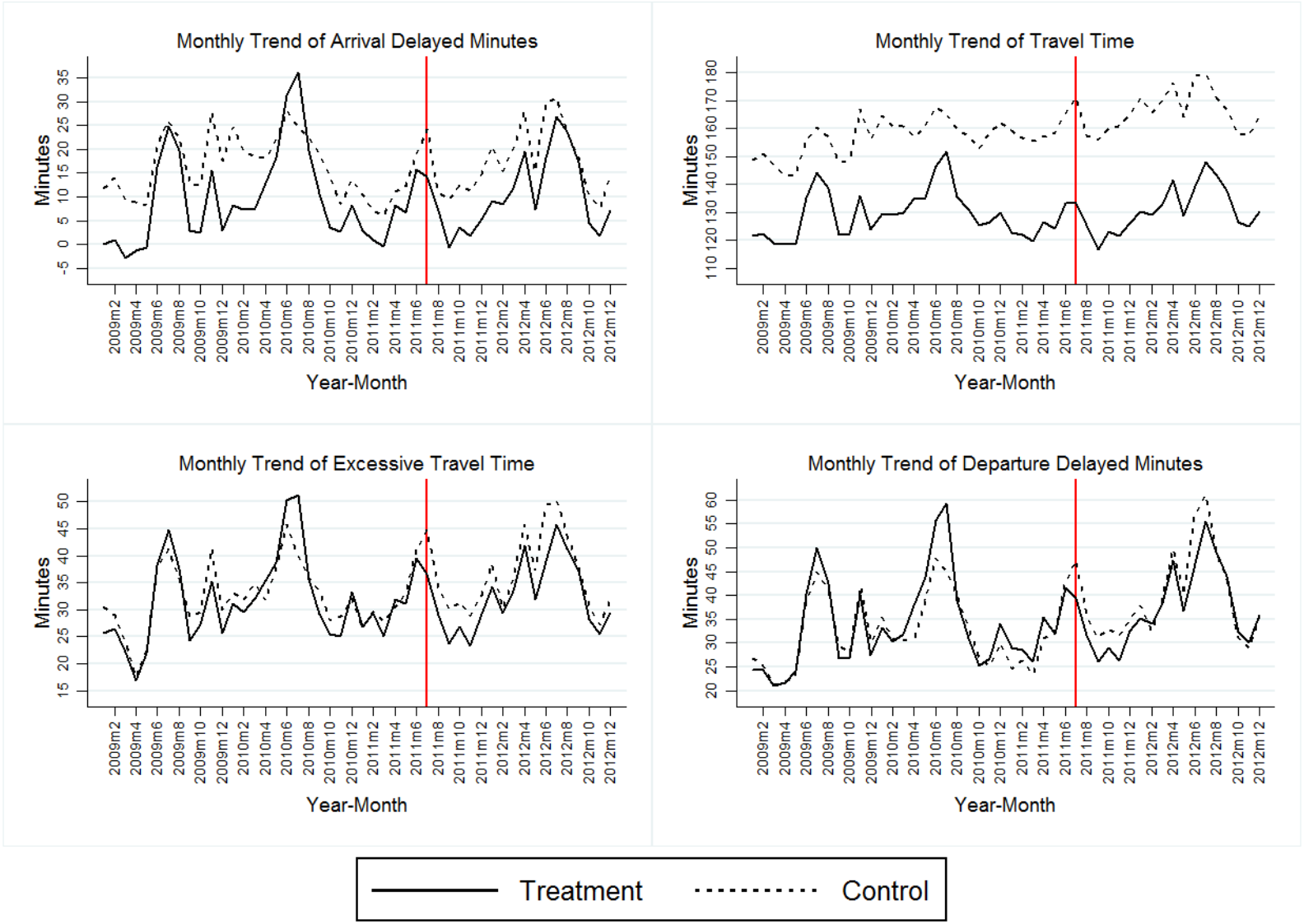
Table 15: Heterogeneity Tests

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*STM					-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
Year-Month 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 the HSR competition effects on hub airlines and distance. Hub is a dummy equal to 1 if the flights are under Air China, China South Airlines, China East Airlines, Hainan Airlines, or Beijing Capital Airlines and 0 otherwise. STM is a dummy equal to 1 if the distance between Beijing and the destination is below 1200 km and 0 otherwise. ADM is short for Arrival Delayed in Minutes. ATT is short for actual travel time. ETT is short for excessive travel time. DDM is short for Departure Delayed in Minutes. The estimations are conducted at the airline-route-month level. The year-month, airline, and route fixed effects are included in all specifications. Standard errors clustered by destinations are reported in parentheses. We use ***, **, and * to denote significance at the 1%, 5%, and 10% levels, respectively.

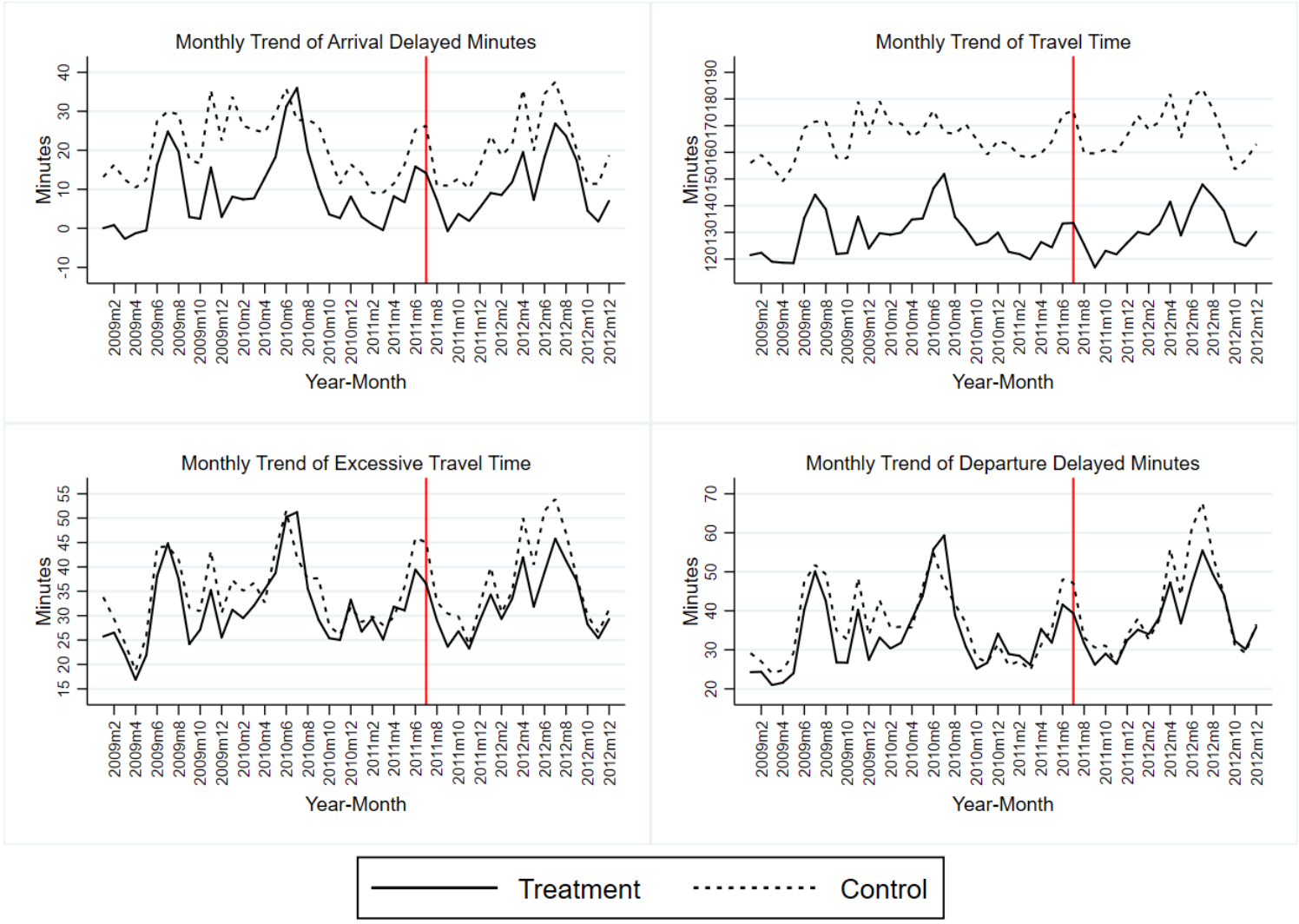
APPENDICES

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



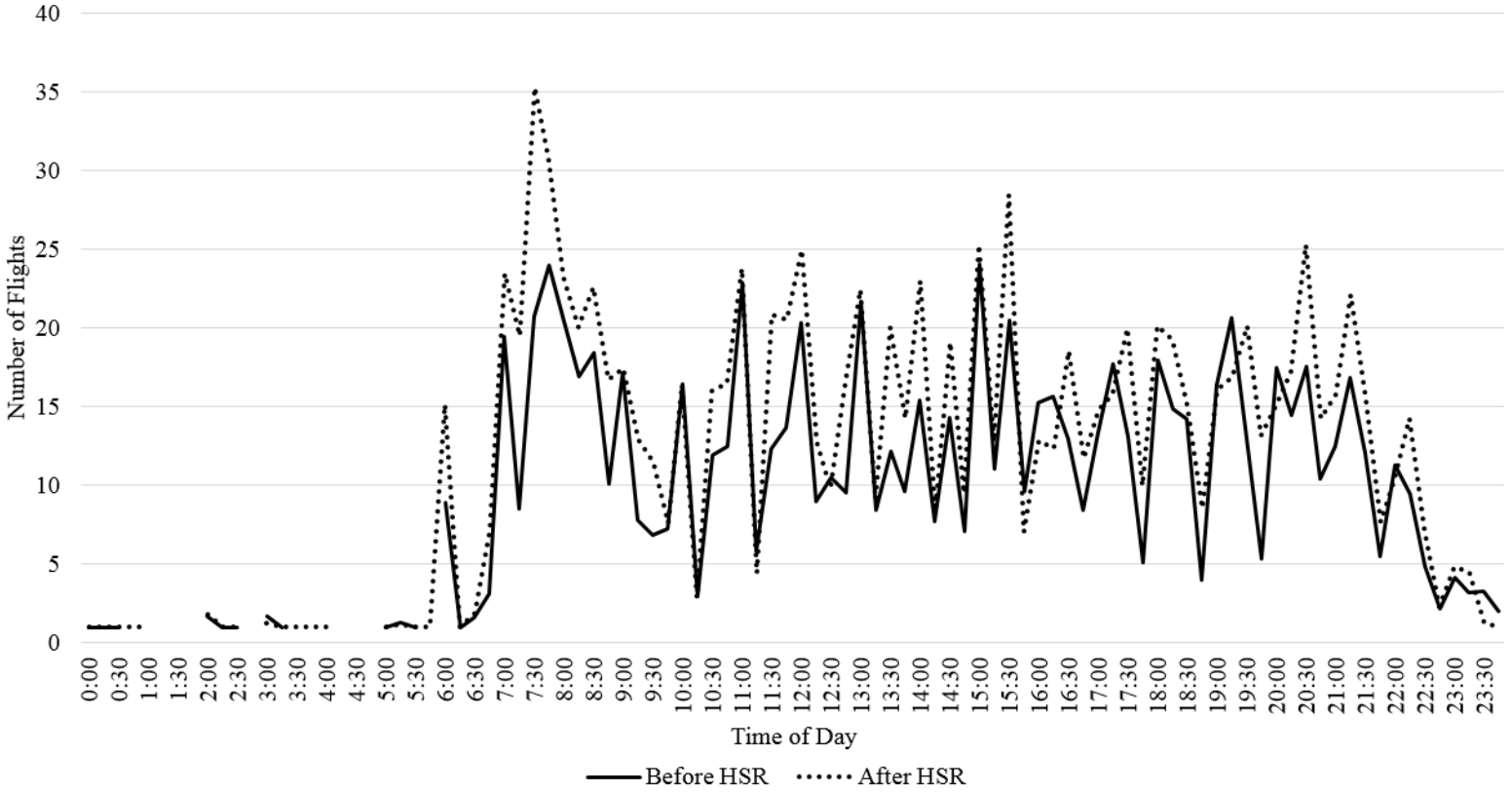
Notes: This figure plots the monthly trends of the four measures of on-time performance for the treated and control groups. The treated group refers to flights departing from Beijing to the 11 destinations denoted by the red railway signs in Figure 1. The control group refers to flights departing from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

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



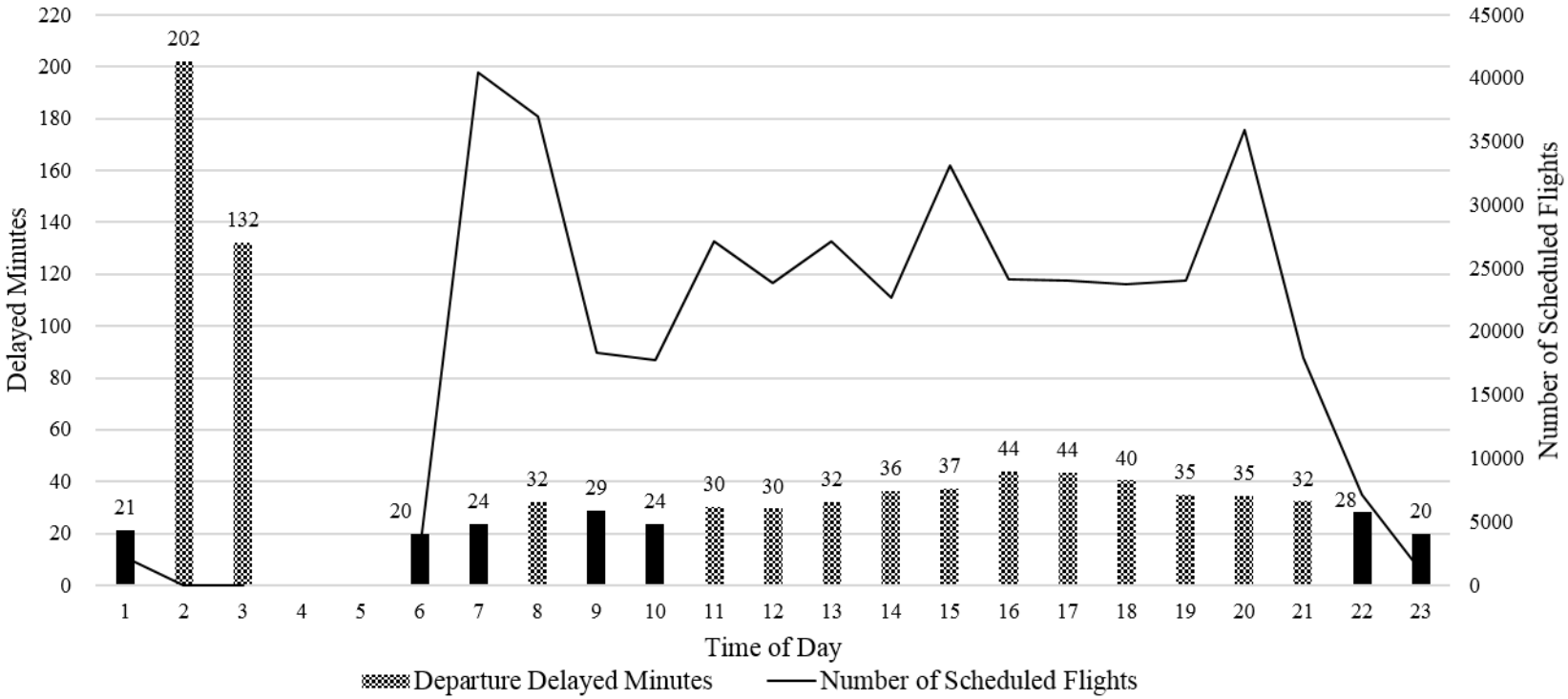
Notes: This figure plots the monthly trends of the four measures of on-time performance for the treated and control groups. The treated group refers to flights departing from Beijing to the 11 destinations denoted by the blue railway signs in Figure 1. The control group refers to flights departing from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

Figure A3: Distributions of the Schedule Time Slots Before/After the HSR Introduction



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

Figure A4: Distribution of the Departure Delay Throughout the Day



Notes: This figure plots the distributions of flights by hour before the introduction of the Beijing–Shanghai HSR line on June 30, 2011. The solid line represents the average departure-delayed minutes by hour. The bar represents the number of flights by hour, with the solid bar denoting the preferred 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 summarizes the cities linked with Beijing by different HSR lines before September 2015. It also reports the province to which an HSR city belongs, the travel time by HSR from Beijing to an HSR city, the distance in kilometers, the entry date, and the official name of the HSR line.

Table B2: Effects of HSR on the Taxi-in/out Time at the Individual Flight and Aggregate Levels

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
Year-Month 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 the HSR introduction on the taxi-out time, taxi-in time, and airtime. The individual- and aggregate-level regressions are presented in each panel. The sample period is from January 2009 to December 2012. The hour, date, and flight fixed effects are included in the individual regressions. The year-month, airline, and route fixed effects are included in the aggregate regressions. Standard errors clustered by destinations are reported in parentheses. We use ***, **, and * to denote significance at the 1%, 5%, and 10% levels, respectively.

Table B3: Effects of HSR on a Delayed Departure of at Least 15/30 Minutes at the 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
Year-Month 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 the HSR introduction on other measures of arrival delays. The individual- and aggregate-level regressions are presented in each panel. The sample period is from January 2009 to December 2012. The hour, date, and flight fixed effects are included in the individual regressions. The year-month, airline, and route fixed effects are included in the aggregate regressions. Standard errors clustered by destinations are reported in parentheses. We use ***, **, and * to denote significance at the 1%, 5%, and 10% levels, respectively.

Table B4: Comparison of the Treated and Control Groups Before the Introduction of the Beijing–Shanghai HSR Line

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

Table 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
Year-Month 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 the nine destinations linked to the Beijing–Guangzhou HSR line introduced on December 26, 2012. The destinations in the artificial treatment group were not linked to the Beijing–Shanghai HSR line between January 2009 and December 2012. In this regression, the 11 actual treated destinations linked to the Beijing–Shanghai HSR line before December 2012 are excluded. The hour, date, and flight fixed effects are included in the individual regressions. The year-month, airline, and route fixed effects are included in the aggregate regressions. Standard errors clustered by destinations are reported in parentheses. We use ***, **, and * to denote significance at the 1%, 5%, and 10% levels, respectively.

Table 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
Year-Month 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 June 30, 2010) one year before the introduction (on June 30, 2011) of the Beijing–Shanghai HSR line. The pre- and post-HSR periods are then set as one year before and after the artificial treatment date. The hour, date, and flight fixed effects are included in the individual regressions. The year-month, airline, and route fixed effects are included in the aggregate regressions. Standard errors clustered by destinations are reported in parentheses. We use ***, **, and * to denote significance at the 1%, 5%, and 10% levels, respectively.