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Competition and Quality:
Evidence from High-Speed Railways and Airlines[†]

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Abstract

The entry of High-Speed Railways (HSR) represents a disruptive competition to airlines, particularly for short- to medium-distance journeys. Utilizing a unique dataset that contains the details of all flights departing from Beijing to 113 domestic destinations in China since January 2009, we employ a difference-in-differences approach to examine the effects of HSR entry on the quality of service provided by airlines as proxied by their on-time performance, and to identify the channels through which competition leads to quality improvement. We document two main findings. First, the competition from the entry of HSR leads to significant reductions in the mean and variance of travel delays on the affected airline routes. Second, the reductions in departure delays–which are controlled mostly by airlines, and the duration of taxi-in time–which are controlled mostly by destination airports, are identified as the main sources of the improvement in the airlines' on-time performance.

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

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

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1 Introduction

There has been a long-standing interest in the effects of competition, which is widely recognized as the drivers of improved product quality, operational efficiency, innovation, and economic growth (Nickell, 1996; Holmes and Schmitz Jr, 2010; Amiti and Khandelwal, 2013; Buccirossi et al., 2013). Establishing a causal impact of competition on productivity or efficiency presents substantial challenges due to the difficulty of identifying a clean source of exogenous variation in competition; it is even more challenging to isolate the mechanisms through which competition impacts quality or productivity (Holmes and Schmitz Jr, 2010). In this paper, we use the entry of Beijing-Shanghai high-speed rails (HSR) as an exogenous increase in competition for the commercial airlines, and investigate whether competition spurs quality improvement, and if so, how.

The entry of High-Speed Railways (HSR) represents a disruptive competition to airlines in the past decade, particularly for short- to medium-distance journeys (Adler et al., 2010; Yang and Zhang, 2012; Fu et al., 2012; Behrens and Pels, 2012; Albalate et al., 2015). Besides its exceptional punctuality, HSR offers improved traveling experiences, stable prices, energy efficiency, and environmental sustainability compared to other modes of intercity transportation.[1] China is a perfect testing ground to analyze the competition between HSR and airlines for several reasons. First, China has the largest and most extensively used HSR network in the world; second, the airline industry in China is rapidly growing both in the number of scheduled flights and passengers, yet it suffers from serious and chronic flight delays which makes HSR a particularly attractive alternative mode of intercity transportation once they are introduced; third, the data on flights' on-time performance (OTP) is available, and OTP is well accepted as the key quality indicator for airlines; fourth, the staggered entries of HSR lines in China offer unique opportunities to address the potential issues of non-random placement of HSRs, and thus offer a clean identification of the causal effects of competition on quality improvement.

More specifically, we argue that the exact date of entry of the Beijing–Shanghai HSR on June 30, 2011 is likely exogenous, and use it to construct treatment and control flights. The Beijing–Shanghai HSR line was the first and only Beijing-outbound HSR line linking Beijing to other cities during our main study period between January 1, 2009 and December 25, 2012. The second Beijing-outbound HSR line, named Beijing–Guangzhou line, began its operations on December 26, 2012, 18 months after the introduction of the Beijing–Shanghai HSR line. Thus, our sample period covers both long pre- and post-HSR time windows, and yet ensures that the estimated treatment effect is free of the possible contamination effects

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[1] The Green New Deal, proposed on February 7, 2019, advocates converting domestic air travel to intercity HSR travel in the US. It calls for a "10-year national mobilization." See `https://apps.npr.org/documents/document.html?id=5729033-Green-New-Deal-FINAL`.

from other Beijing-outbound HSR entries. To address the concern that cities on the Beijing-Shanghai HSR are selected, we as a robustness test also limit our control flights to a subset of destination cities that are on the Beijing-Guangzhou line. The Beijing-Shanghai line and the Beijing-Guangzhou line were planned at the same time, and their constructions were also initiated in the same year; but the former began operating 18 months earlier only because it was shorter and thus construction was finished sooner.[2]

In this study, we use a proprietary and comprehensive dataset containing 865,967 non-stop Beijing-outbound flights scheduled by 41 airlines to 113 domestic destinations in China between January 1, 2009 and December 25, 2012. The richness of this flight data enables us to study the impact of HSR competition on the airlines' quality improvement proxied by their OTP, and to pinpoint the sources of the quality improvement. We use a difference-in-differences (DID) strategy that exploits the variation in competition caused by HSR entry across cities. The treatment group is flights that depart from Beijing Capital International Airport (BCIA) for cities connected by the Beijing-Shanghai HSR, and the control group is flights departing from Beijing for non-HSR destinations. Following Mayer and Sinai (2003) and Prince and Simon (2015), we employ four different OTP measures as outcome variables, namely, the Arrival Delay Minutes (the difference between the actual arrival time and scheduled arrival time, which measures the intensive margin of the flight delay), an indicator for whether a flight arrives 15 minutes later than the scheduled arrival time (which measures the extensive margin of the flight delay), as well as the actual travel time and excessive travel time.

When we compare the OTP of the Beijing-outbound flights to the 11 destination cities on the Beijing-Shanghai HSR (the treatment group) with Beijing-outbound flights to 102 non-HSR destinations (the control group) from January 1, 2009 to December 25, 2012, we find that, at the intensive margin, the HSR entry leads to an average decrease of 2.54 minutes (about 14.51%) in arrival delay minutes; and at the extensive margin, the HSR entry causes a 2.5 percentage points reduction in arrival delays of 15 minutes or longer. We also find that the entry of HSR significantly reduces the variance of flight arrival delay minutes. These results are quantitatively similar when we restrict our control group to Beijing-outbound flights to the nine cities on the Beijing-Guangzhou HSR that opened on December 26, 2012.

To identify the source of improvement in quality, we investigate the impact of competition on each breakdown of flight schedule.[3] We find that HSR entry leads to an average reduction in *departure delay* by 5.28 minutes, which accounts for the largest decline among

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[2] See Table A1 in the Appendix for the gradual expansion of China's HSR system. Source: `https://www.travelchinaguide.com/china-trains/high-speed/rail-network.htm`

[3] 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).

all contributors to the post-HSR reduction in arrival delay minutes. In addition, HSR entry leads to a reduction of the *taxi-in time* of 1.39 minutes on average at the destination airports that are impacted by the HSR.

We consider and rule out a variety of alternative explanations for our findings. First, to address the possible contamination from the treatment to the control flights, we test the impact of the HSR entry on *air time* and find that the HSR entry does not cause congestion in the air corridor for the control flights. Second, to address the concern that the reduction in arrival delays might be the result of a deliberately prolonged scheduled duration, rather than a genuine improvement in OTP, we test the impact of the HSR entry on *scheduled duration* and rule out this alternative explanation. Third, to examine whether a reduction in the number of passengers on the treatment flights, which leads to faster check-ins, could drive our findings, we use a subsample of flights during China's holiday period when we are ensured that all airports and airlines operate at full capacity. We still find that the HSR entry leads to significant reductions in fight delays. Fourth, to address the possibility that our results are driven by some flights with more serious delays being either eliminated or being re-assigned with new flight numbers, we focus on a subsample of flights that existed both before and after the HSR entry. We find that the improvement in the OTP of treated fights remains in this subsample of flights. We also consider and rule out other alternative explanations, such as more favorable military/air traffic control and more favorable scheduling to less busy time slots, among others. Finally, we conduct placebo tests using a fictitious treatment group, or a fictitious treatment date, and both placebo tests confirm that the competition effects we estimated are not caused by other spurious factors.

The richness of our flight data also allows us to better understand the heterogeneity in the service quality response to the competition from the HSR entry. We find that non-hub airlines and flights on short-to-medium routes (air distance within 1,200 km) are more responsive to HSR entry than their respective counterparts. We also extend our analysis to cover the sample period up to September 2015, by when 10 additional HSR lines were introduced.[4] We find that our results are robust to the extension of the larger sample. Finally, we conduct a back-of-the-envelope calculation of a lower bound of the monetary value of the time saving for air travelers on the routes affected by the HSR entries.

This study adds to the literature that examines the causal effects of competition. Nickell (1996), Schmitz Jr (2005) and Matsa (2011) present evidence of the positive effects of competition on productivity and product quality, while Gal-Or (Gal-Or) suggests a negative relationship. Aghion et al. (2005) and Hashmi (2013) document an inverted-U relationship

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

between import competition and innovation, whereas Cornaggia et al. (2015) reveal a negative impact of bank competition on innovation. Our findings also complement the literature on airline competition. An extensive amount of empirical work shows that competition within the airline industry improves the OTP 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, ours is the first study that provides causal empirical evidence for how airline OTP is affected by a plausibly exogenous competition shock from a different sub-sector in the transportation industry.

This study also contributes to the growing literature on the economic impacts of transport infrastructure projects. Much of the literature explored the effects of urban transportation improvements in roads and railways on urban growth, urban form, congestion, and trade cost (Baum-Snow, 2007; Duranton and Turner, 2011, 2012; Baum-Snow et al., 2017; Donaldson, 2018). In addition, the literature has show that HSR has a positive influence on intercity mobility (Chen, 2012; Tierney, 2012), market integration (Zheng and Kahn, 2013), population density, and employment (Lin, 2017; Levinson, 2012). However, some studies argue that HSR primarily benefits large cities, as opposed to small counties (Zheng and Kahn, 2013; Qin, 2017). Moreover, recent studies that examined the impacts of HSR on the airline industry focus on the market share and price response (Behrens and Pels, 2012; Yang and Zhang, 2012; Fu et al., 2012). This study contributes to this strand of literature by examining the causal impacts of China's HSR on the *non-price* characteristics of the airline industry, which provides policy implications for other countries that may be contemplating to build a HSR network.

The remainder of the paper is structured as follows. In Section 2, we provide a brief background on the HSR networks and the airline industry in China. In Section 3, we describe our dataset and present summary statistics. In Section 4, we present our empirical strategies and the main results. In Section 5, we discuss various alternative explanations and present falsification tests. In Section 6, we provide a back-of-the-envelope calculation for a lower bound estimate of the time value from the improvement in OTP. Finally, in Section 7, we conclude.

2 Background on the HSR and Flight Delays in China

After 20 years of development and expansion, China's high-speed railways, which are designed for speeds of 250 to 350 Kilometers per hour (kph), have become the largest and most extensively used HSR network in the world. China's HSR network plan, which is often dubbed "the Eight Vertical and Eight Horizontal plan," is based on eight major HSR lines from the north to the south (the eight "verticals"), and another eight major HSR lines from the east to the west (the eight "horizontals"). Beijing is regarded as the most crucial starting point of the vertical lines.

The Beijing–Shanghai HSR line is the first medium- and long-haul Beijing-outbound HSR track that links Beijing to 26 other domestic destinations (see Table A1 in the Appendix).[5] 11 of the 26 cities are linked with Beijing by non-stop commercial flights.[6] The Beijing-Shanghai HSR operates 45 trips in each direction on a daily basis. The opening of Beijing-Shanghai HSR reduces the traveling time by train from around 13 hours to 4-5 hours for the 1,318 km journey. Given that a direct flight between the two cities takes about two hours of air time, so even with the longer travel time from the city to the airport than to the train station and the longer boarding time for flights, train travel was clearly a much more time-consuming option prior to the HSR entry. However, the introduction of the Beijing–Shanghai HSR line on June 30, 2011 changed the situation completely by reducing the HSR travel time substantially; moreover, the HSR is almost always punctual by the minute. In this sense, we interpret the entry of HSR as a serious competition to the airline industry, particularly for short-to-medium distance journeys.

The Chinese airline industry has experienced tremendous growth in the past 30 years, with air passenger traffic growing from 18.2 billion in 1987 to 837.8 billion in 2016.[7] Despite this huge growth, China's airline market is still in its nascent stage, and suffers from poor operational efficiency and management. According to the 2018 world airport punctuality report, none of China's airports is ranked in the top 20 in terms of OTP.[8]

In this study, we focus on the flights departing the Beijing Capital International Airport (BCIA). BCIA has been the world's second busiest airport in terms of passenger traffic since 2010, but it ranked only 44th out of China's 76 international airports in punctuality as of 2017. Specifically, of the 286,602 flights departing BCIA in 2017, only 53.7% departed on time, and departure delays averaged at around 48.5 minutes.[9] The chronic and often unpredictable delays in BCIA are one of the major complaints from travelers through BCIA.

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[5] Spanning a distance of 117 km, the Beijing–Tianjin HSR line is the first Beijing-outbound HSR. However, owing to the short distance, there are no flights between Beijing and Tianjin.

[6] These 11 cities are Changzhou, Hangzhou, Hefei, Jinan, Nanjing, Ningbo, Qingdao, Shanghai, Wenzhou, Wuxi, and Xuzhou, which are denoted by the red train signs in Figure 1.

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

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

[9] The number is calculated using the data collected from Feichangzhun. Source: `https://data.variflight.com/analytics/OTPRankingbyAirport`.

3 Data and Summary Statistics

The flight data used in this analysis was obtained from a leading data company that focuses on commercial aviation. The dataset in the baseline analysis contains 865,967 non-stop flights, scheduled by 41 airlines, departing from Beijing to 113 domestic destinations between January 1, 2009 and December 25, 2012.[10] Figure 1 presents the 113 destinations (denoted by the red, green and black train signs, as well as the blue airport signs) that have non-stop flights from Beijing. Focusing on the sample period between January 1, 2009 and December 25, 2012 ensures that the Beijing–Shanghai HSR line, which opened on June 30, 2011, is the only Beijing-outbound HSR in the analysis; it also guarantees a sufficiently long pre- and post-HSR time window. To ensure that the results can be generalized to the full sample, we repeat the main analysis using an expanded sample from January 2009 to September 2015. In one of the robustness checks, we also use international flights as a control group.

[Figure 1 About Here]

For each flight in our sample period, we have the flight number, flight date, scheduled departure and arrival times, actual gate departure and gate arrival time stamp, 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*). We illustrate the various components of flight duration in Figure 2. Following Prince and Simon (2015), we define a *route* as a directional Beijing–destination pair for any carrier that provides non-stop services. For instance, for flight CA1515, the destination city (e.g., Shanghai) refers to a route, CA (China Air) stands for an airline company, and CA1515 represents a flight.

[Figure 2 About Here]

Following the existing literature, we construct two measures of OTP for both the arrival and departure delays (Mayer and Sinai, 2003; Goolsbee and Syverson, 2008; Prince and Simon, 2009, 2015). Specifically, *Arrival Delay in minutes* (ADM) represents the difference between the scheduled and the actual arrival times. *Arrival Delay 15 minutes* (ADD15) is a dummy variable equal to 1 if a flight arrives at the gate at least 15 minutes late, and 0 otherwise. We use the same approach to construct *Departure Delay in minutes* (DDM) and *Departure Delay 15 minutes* (DDD15).

To address the possibility that airlines could manipulate the OTP by artificially inflating the scheduled duration (Mayer and Sinai, 2003; Prince and Simon, 2015), we construct two alternative measures of OTP: *Actual Travel Time (ATT)* and *Excessive Travel Time (ETT)*. *ATT* is the time difference between the scheduled departure time and the actual arrival time, which measures the actual travel time because any passenger needs to be at the gate

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[10] Cities without direct flights from Beijing are excluded from the analysis.

before the scheduled departure and will not leave the gate at the destination until the actual arrival time. ETT is the difference between ATT and the minimum feasible travel time. The minimum feasible travel time refers to the minimum travel time of the same flight observed each month, which serves as a benchmark for determining the travel time when a flight is free of any external influences such as air congestion, weather shocks, and air corridor military controls. Therefore, ETT controls for any unobserved or observed time-varying external influences and is immune to airline scheduling manipulations. In Figure 3, we plot the distributions of ATT for the Beijing-outbound flights to the 11 destination cities along the Beijing-Shanghai HSR, as well as that of the HSR trains.[11] Figure 3 shows that the ATT for flights (denoted by the black lines) exhibits large variations.

[Figure 3 About Here]

In Table 1, we provide the summary statistics of the OTP measures and other variables at the individual flight level. In the post-HSR period, the mean values of *ADM*, *DDM*, ATT, and ETT increase for both the treatment and control flights, which is a reflection of the rapid growth of the passenger travel industry in China. But it is interesting to note that the increases in the treatment group are smaller. The summary statistics at the aggregated airline-route-month level (12,499 airline-route-month observations) are reported in Table A2 in the Appendix.

[Table 1 About Here]

4 Empirical Strategies and Main Results

In this section, we first present evidence that the HSR entry poses real competition to the airline industry on the impacted routes. We then describe our empirical strategies, the main empirical results, and various robustness checks.

4.1 HSR Entry as a Competition Shock: Evidence from Supply-Side Response

We have argued that HSR is a disruptive transportation technology that poses competition to air travel, particularly for short-to-medium distance journeys. In this subsection, we provide direct evidence that the HSR entry indeed is a competition shock to the airline industry by examining the supply-side response of the airlines. Specifically, we examine the impact of HSR entry on the number of flights operated in a given route at the flight-month,

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[11] According to the latest World Bank report, the punctuality rate of HSR service in China is over 98 percent for departures and over 95 percent for arrivals. Source: `https://openknowledge.worldbank.org/handle/10986/31801`. Therefore, we consider the travel time invariant for HSR travel, which is denoted by the red vertical line in Figure 3.

the airline-route-month, and the route-month levels. To study the average monthly flight supply responses to the Beijing-Shanghai HSR entry, we run the following regressions:

$$Y_{i,m} = \alpha + \beta \cdot \mathit{Treatment}_i \cdot \mathit{After}_m + \mu_i + \gamma_m + \epsilon_{i,m}, \tag{1a}$$

$$Y_{j,d,m} = \alpha + \beta \cdot \mathit{Treatment}_{j,d} \cdot \mathit{After}_m + \theta_j + \eta_d + \gamma_m + \epsilon_{j,d,m}, \tag{1b}$$

$$Y_{d,m} = \alpha + \beta \cdot \mathit{Treatment}_d \cdot \mathit{After}_m + \eta_d + \gamma_m + \epsilon_{d,m}, \tag{1c}$$

where i, j, d, and m index the flight number, the airline, the route (or destination), and year-month, respectively. $Y_{i,m}$, $Y_{j,d,m}$, and $Y_{d,m}$ represent the number of flights by flight-month, by airline-route-month, and by route-month, respectively. $\mathit{Treatment}_i$, $\mathit{Treatment}_{j,d}$, and $\mathit{Treatment}_d$ are dummy variables that takes value 1 if the flight i, the airline-route (j, d), and the route d, respectively, belongs to the 11 HSR destinations connected to Beijing by the Beijing-Shanghai HSR. After_t is a dummy variable that takes the value 1 after June 30, 2011, and 0 otherwise. Flight fixed effect μ_i is included in Eq. (1a); airline fixed effects θ_j and route (or destination) fixed effects η_d are included in Eq. (1b); and the route (or destination) fixed effects η_d are included in Eq. (1c). Year-month fixed effects γ_m are included in all three equations. The standard errors are clustered at the flight-, airline-route-, and route-level in Eqs. (1a), (1b) and (1c), respectively.

Table 2 reports the results. It shows that the coefficients for the interaction terms are negative and statistically significant, suggesting that the number of flights to the treated destination cities decreases by 8.42% ($= 1 - \mathit{exp}(-0.088)$) to 17.47% ($= 1 - \mathit{exp}(-0.192)$) more than that of control destination cities in the post-HSR period. The results are consistent with both the anecdotal evidence and the findings in Fu et al. (2012).[12] We consider the relative reduction in flight supply as direct evidence that the HSR entry poses a serious competition shock to the airlines.[13]

[Table 2 About Here]

4.2 HSR Entry and Flight Delays: Baseline Results

Our basic specification to examine the causal effects of the Beijing-Shanghai HSR entry on the OTP of the treated flights is a difference-in-difference (DID) regression at individual-flight level:

$$\mathit{Delay}_{i,j,d,t} = \alpha + \beta \cdot \mathit{Treatment}_{i,j,d} \cdot \mathit{After}_t + \mu_i + \delta_{hour} + \zeta_t + \epsilon_{i,j,d,t}, \tag{2}$$

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

[13] However, as we will show in Figure A2 , the overall number of flights departing BCIA has been going up in this period because the Chinese air travel industry is proliferating.

where $Delay_{i,j,d,t}$ is one of the four OTP measures for flight i of airline company j departing from Beijing to destination d on date t. *Treatment* is a dummy variable equal to 1 for treated flights. 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 the unobserved factors that may affect flight delays at the flight level. The term δ_{hour} represents the hourly fixed effects, which account for any hourly variations that may affect flight delays, such as the airport congestion and weather conditions. We also include the date fixed effects ζ_t to eliminate any seasonal and national trends. The standard errors are clustered at the destination city level to capture the potential heteroskedasticity of the error terms across the destination cities.

[Table 3 About Here]

Table 3 presents the estimation results for Eq. (2). The estimated coefficients on $Treatment \cdot After$ are consistently significantly negative in all columns, which suggests that flights facing the new competition from the HSR entry improve their OTP in the post-HSR period relative to control flights. Specifically, at the intensive margin (as shown in Columns 1 and 3), on average, the HSR entry reduces the arrival and departure delays for the treatment flights by 2.54 minutes (about 14.51%) and 5.28 minutes (about 14.47%) more than for the control flights. At the extensive margin (as shown in Columns 2 and 4), treated flights in the post-HSR entry period are less likely than the control flights to experience arrival (departure, respectively) delays longer than 15 minutes, by 2.5 (3.4, respectively) percentage points. Using the alternative measures of OTP in Columns 5 and 6, we find very robust results indicating that the HSR entry reduces actual travel time (*ATT*) and excessive travel time (*ETT*) by 4.73 and 3.92 minutes, respectively.

Table A3 in the Appendix reports the estimation results when we include route fixed effects interacted with the year-month fixed effects and airline fixed effects interacted with the year-month fixed effects to address any omitted factors at the route (or destination) and airline level. The results are consistent with our baseline results in Table 3.

4.3 Parallel Pre-Trends and Dynamic Effects of the HSR Entry

In this subsection, we verify the parallel pre-trend assumption that is necessary for the validity of the DID approach we used in estimating Eq. (2). We estimate the following equation to verify the parallel pre-trends between the treatment and control flights, and to capture the dynamics of the improvement of the OTP to the entry of the HSR:

$$Delay_{i,j,d,t} = \alpha + \sum_{s=-4}^{s=5} \beta_s \cdot Treatment_{i,j,d} \cdot 1\{t \in Quarter_s\} + \mu_i + \delta_{hour} + \zeta_t + \epsilon_{i,j,d,t} \tag{3}$$

where $t \in Quarter_s$ is a binary indicator which takes value 1 if the date t is in quarter $s \in \{-4, -3, -2, ..., 0, ..., 3, 4, 5\}$ before/after June 30, 2011. The coefficient β_s measures the difference in the response of OTP compared with the first 12 months (benchmark period from January 1, 2009 to December 31, 2009) in our sample period between the treatment and control flights. More specifically, the coefficient β_0 measures the immediate response in OTP during the quarter of the HSR entry. The coefficients $\beta_1, \dots, \beta_5$ measure the responses in the first to the fifth quarter following the entry of HSR, respectively. Similarly, coefficients $\beta_{-4}, \dots, \beta_{-1}$ capture the different trends of OTP response between the treatment and control flights in each of the four pre-treatment quarters. We plot the estimated coefficients of β_s for different measures of OTP in Figure 4. It shows that the treated flights start responding to the entry of the Beijing-Shanghai HSR immediately after the introduction; and the effects are persistent.

[Figure 4 About Here]

Figure 4 also shows that the parallel pre-trend assumption holds, as the $\beta_{-4}, ..., \beta_{-1}$ coefficient estimates are statistically indistinguishable from 0, indicating that there is no systematic difference in pre-trends between the treatment and control flights in their OTP measures.

4.4 Effects on the Variance of the Delays

The HSR entry may also result in a reduction in the variance of the delay minutes of the treated flights, which can lead to substantial welfare gains if travelers are particularly wary of unpredictable long delays. To examine the effect of HSR entry on the variance of flight delays, we first compute, for each flight, the weekly variance of the OTP measures, ADM, DDM, ATT and ETT; we then use them as the dependent variables in the DID analysis, similar to the regression specification of Eq. (2), except that we control for the year-week and flight fixed effects, instead of hour and date fixed effects. We also cluster the standard errors at the destination city level. Table 4 reports that the interaction term $Treatment \cdot After$ is negative and statistically significant, with the magnitude of the estimates indicating that the standard deviation of the delays of the treatment flights reduces by around 23 to 24 minutes after the HSR entry. This suggests that the HSR entry reduces the unpredictable long delays of the treatment flights.

[Table 4 About Here]

4.5 Robustness Tests

Aggregate-Level Analysis. Our baseline results are conducted at the individual flight level. To the extent that some flights may be eliminated or re-assigned, it is useful to verify the robustness of our results at the airline-route-month level. For example, Air China flight CA0000 from Beijing to Shanghai was changed to CA0123 in our sample period; the individual flight level analysis will not be able to recognize that CA0000 and CA0123 are in fact the same light.[14] To deal with the complications from such unobserved changes, we aggregate our individual-flight level data into the *airline-route-month* level using the following specification:

$$Delay_{j,d,m} = \alpha + \beta \cdot Treatment_{j,d} \cdot After_m + \theta_j + \eta_d + \gamma_m + \epsilon_{j,d,m} \tag{4}$$

where $Delay_{j,d,m}$ is the *average* delay for airline company j departing from Beijing to destination city d in month m. In the aggregate-level regressions, we control for airline fixed effects, route (destination city) fixed effects, and year-month fixed effects. We estimate weighted least squares (WLS) models using the number of flights on each airline route each month as the weight in the respective cells (Prince and Simon, 2009, 2015). The results are reported in Table 5. Consistent with the baseline results, the coefficients on the interaction terms $Treatment_{j,d} \cdot After_m$ are negative and significant in all columns. The results are also quantitatively similar to the results obtained at the individual flight level: the HSR entry leads to 3.4 minutes reduction in the average arrival delay minutes of treated flights relative to the control flights.

[Table 5 About Here]

A Narrower Control Group. In our baseline analysis, we assumed that the placement of Beijing-Shanghai HSR is exogenous. Even though we provided evidence of parallel pre-trend between the control and treatment flights in Figure 4, one may still be concerned that the 11 destination cities affected by the Beijing-Shanghai HSR – the treatment group – are different from the 102 destination cities in the control group, on factors such as the local economy, industry distribution, and geographic characteristics. Such differences *per se* are not an issue for DID approach to work, provided that parallel pre-trend assumption is satisfied. However, to ensure more comparable treatment and control groups, we create a narrower control group consisting of only the 9 destination cities (indicated by the green train signs in Figure 1) along the Beijing–Guangzhou HSR line, which started operating on

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[14] In Section 5, we will also report results where we only include flights that appeared in both the pre- and post-HSR entry periods. The results are robust.

Dec. 26, 2012.[15]

Cities located along the Beijing–Shanghai and Beijing–Guangzhou HSR lines are definitely more comparable; in particular, both lines were initiated in the same plan in 2004, and their constructions started at the same time in October 2008.[16] The Beijing–Guangzhou line was completed 18 months after the Beijing–Shanghai line only because of the difference in length: the Beijing-Guangzhou and Beijing-Shanghai HSR lines are respectively 2,298 km and 1,318 km in length. Indeed, as we report in Table A4 in the Appendix, the difference between the treatment and control destinations in the key economic variables, such as population, income, GDP, and the number of flights, etc. are economically small and statistically indistinguishable from zero.

Table 6 reports the estimation results using the narrower control group. The estimated treatment effects β are statistically different from zero in all columns and the OTP improves by 2.2 to 3.6 minutes depending on the delay measures. The results are both qualitatively and quantitatively consistent with the baseline results reported in Table 3.

[Table 6 About Here]

4.6 Sources of On-time Performance Improvement

Tables 3 and 6 show that the airline industry reduces the mean and variance in flight delays in response to the competition from the HSR entry. In this section, we attempt to isolate the components in air travel, as depicted in Figure 2, that constitute the main contributing sources of potential OTP improvement. As illustrated in Figure 2, we decompose the *Actual Travel Time* (actual arrival time minus the scheduled departure time) into two parts: *actual duration* for flight and *departure delay*; and we can further decompose the *actual duration* into *taxi-out time*, *air time* and *taxi-in time*. Note that the different components are subject to the control of different parties: the *departure delay*, which measures the delay before leaving the gate, is mostly under the airlines' control (Prince and Simon, 2009); the *taxi-out time* and *taxi-in time* are, respectively, mostly under the control of the departing and destination airport authorities; and *air time* is difficult to improve upon without sacrificing safety or changing the plane models. Thus we expect that the major source of the OTP improvement will be the reduction in *departure delay*.

In Column 1 of Table 7, we find that *departure delay* decreases by 5.28 minutes in response to the HSR entry. The coefficient is negative and statistically significant at the 1% level. This confirms our intuition discussed above, as airlines could reduce the departure delay by accelerating the check-in and boarding process and by better training the aircrews.

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[15] These nine cities are: Zhengzhou, Taiyuan, Luoyang, Wuhan, Yichang, Changsha, Xian, Guangzhou, and Shenzhen.

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

In Column 2 of Table 7, we find that indeed, the HSR entry does not seem to have a statistically significant impact on the *actual duration*. In Columns 3-5 we examine the three sub-components of *actual duration*, namely, *taxi-out time*, *air time*, and *taxi-in time*. The results are somewhat surprising: we find that the HSR entry had a statistically significant negative effect on *taxi-in time* and a statistically significant positive effect on *air time*. Since the *taxi-in time* is likely to be substantially controlled by the airport authorities (Prince and Simon, 2009), the result that the HSR entry reduces *taxi-in time* at a significant magnitude (1.39 minutes on average) at the destination airports suggests that the destination airports strive to optimize the usage of the runway resources in the post-HSR period for the treated flights.

[Table 7 About Here]

4.7 More HSR Entries After December 26, 2012

Between December 26, 2012 and September 2015, 10 additional HSR lines entered service in China. The number of destination cities that are connected to Beijing by HSR lines increased from 11 to 33 during this period (see Table A1 in the Appendix for more details). We examine the effects of all the HSR entries on the treated flights in this subsection. Extending the analysis to include more HSR entries can also help us to address the concern that the early HSR lines are selected to connect Beijing to the destination cities with the most serious flight delays: if so, we would expect that the estimated treatment effects will be smaller when we include later HSR entries in the analysis.

Table 8 reports the results of regressing the different measures of OTP in the same specification as Eq. (2) in the enlarged sample. The estimated coefficients of the interaction term $Treatment \cdot After$ are both qualitatively and quantitatively consistent with our estimates reported in Table 3. This provides additional evidence against the concern that the baseline results reported in Table 3 are driven by the Beijing-Shanghai HSR line being non-representative.

[Table 8 About Here]

4.8 Heterogeneity Effects

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

Hub airlines at BCIA may enjoy more market power than their non-hub peers, as a result, hub and non-hub airlines may respond differently to the competition from the HSR entry. According to the Civil Aviation Administration, China Air, China Southern Airlines, China Eastern Airlines, Hainan Airlines, and Beijing Capital Airlines are the hub airlines of BCIA.

Panel A of Table 9 presents the estimated heterogeneity of the hub and non-hub flights. *Hub* is a dummy equal to 1 if the flights belong to one of the five hub airlines, and 0 otherwise. We use the sample period from January 2009 to September 2015 in this estimation. The estimated coefficients on $Treatment * After * Hub$ are significantly positive for all measures of OTP, indicating that non-hub airlines are more responsive to the competition from the HSR entry.

[Table 9 About Here]

Since the introduction of HSR imposes the most fierce competition for air routes within 1,200 km (Fu et al., 2012; Yang and Zhang, 2012), we use 1,200 km as a cutoff to categorize flights into short-to-medium-haul and long-haul routes.[17]

Panel B of Table 9 presents the results. *STM* is a dummy equal to 1 if the distance between Beijing and the destination city is below 1,200 km, and 0 otherwise. The estimated coefficients of $Treatment * After * STM$ are significantly negative for all four measures of OTP, implying that short-to-medium-haul flights are more responsive to competition from HSR lines. Instead of using *STM* dummy, we also create indicators of different distance categories. Figure 5 plots the coefficients of OTP response for the treatment flights for the entire distribution of travel distances, ranging from 500 km to over 1,500 km, along with their corresponding 95 percent confidence intervals. The coefficient estimates plotted in Figure 5 shows that, on average, the OTP improvement of treated flights upon the HSR entry is the largest for short-haul flights.

[Figure 5 About Here]

5 Alternative Explanations and Falsification Tests

In this section, we consider several alternative explanations for our main findings reported in Section 4, and also offer two falsification tests to further establish the causality of our findings.

5.1 Alternative Explanations

Corridor and Airport Congestion. One concern is that, in response to the HSR entry, airlines may allocate flights from treatment routes, i.e., routes that are now subject to the

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[17] According to Sachs (2010), HSR trains is the most efficient for journeys from three to four hours. Thus, HSR trains impose the most fierce competition for journey distance within 1,200 km, given the average HSR speed of 300 kph. Thus, the launch of the Beijing–Shanghai HSR line serves as the strongest competition to the airline routes between Beijing and the 11 destination 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.

HSR competition, to control routes. This may cause air corridor congestion in the control routes and leads to a decrease in the OTP for the control flights. However, this alternative hypothesis is inconsistent with our finding reported in Column 5 of Table 7, where we use the *air time* as the dependent variable. We find that the HSR entry causes the *air time* of the treatment flights to increase by 1.74 minutes on average relative to the control flights. This suggests that air corridor congestion in the control routes is unlikely the source for our main finding as reported in Table 3.

In addition, we directly examine whether the HSR entry affects the allocation of the departure hours of the control and treatment flights across different hours of the day. Figure A1 in the Appendix plots the distribution of flights per hour at BCIA before and after the HSR entry. We observe a similar number of treatment and control flights departing throughout the day in the post-HSR period, especially in the peak hours (1am, 6am, 7am, 9am, 10am and 10–11pm). This suggests that our main findings in Table 3 are unlikely due to the differential impact on the congestion delays in BCIA of the treatment and control flights upon the HSR entry.

Schedule Manipulation. Another alternative explanation is that our finding of the reduced arrival delay minutes may be the result of a deliberately prolonged scheduled duration, rather than an genuine improvement in the OTP, of the treated flights (Mayer and Sinai, 2003; Prince and Simon, 2015). However, this alternative explanation is inconsistent with Column 6 of Table 7, where we report the response of *scheduled duration* to the HSR entry of the treatment flights. We find that the estimated coefficient β for the interaction term is not statistically significant, implying that the treatment flights do not adjust the scheduled duration differentially from the control flights.

Fewer Air Travelers on the Treated Flights. Another alternative explanation for our finding is simply that the treatment flights have fewer passengers after the HSR entry; fewer passengers on the treatment flights can lead to faster check-in and boarding process, resulting in a reduction in departure delays and better OTP.

To address this alternative explanation, we use a subsample of flights around the three most important Chinese *holidays*, specifically, the Spring Festival, the Mid-Autumn Day, and the National Day. Due to the large scale migrant population movements around these holidays, all modes of transportation, including airplanes, HSR, and intercity buses operate at full capacity; thus for flights around these holidays, whether they are on the treated routes or the control routes, the concern that fewer passengers on the treated flights is no longer relevant.

Specifically, we restrict ourselves to a subset of the 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. The numbers of travelers taking flights during holiday periods are comparable before and after the HSR entry. Table 10 shows significantly negative treatment effects in this holiday subsample analysis, indicating that the decrease in the departure delay is due to the entry of the HSR, rather than to a reduction in the number of air travelers.

[Table 10 About Here]

Flight Cancellation. Another alternative explanation is that, upon the HSR entry, the airlines might have permanently culled some flights with poor OTP; thus, our findings could result from a mechanical compositional change of the surviving flights, rather than genuine quality improvement.

To address this concern, we re-estimate Eq. (2) using only the subsample of flights that operated continuously both before and after the HSR entry. We report the results in Table 11, and find that our findings are quantitatively and qualitatively robust to this subsample analysis.

[Table 11 About Here]

Delays of the Previous Flights. A further alternative explanation for our finding is that the control flights in the post-HSR period experience more delays due to the delays of incoming flights (so called "snowball" delays). We already controlled for flight hour fixed effects in Eq. (2), but to further address this concern, we focus on a subsample of the flights that depart from BCIA in the early morning (6 am to 9 am). It is well known that fights departing early in the morning are less likely to be delayed due to the delays of the incoming flights. The results in Table 12 show that the estimates of the interaction term are significantly negative in all columns in this subsample analysis, with similar magnitudes.

[Table 12 About Here]

Rescheduling to Less Congested Time Slots. Another alternative explanation is that, facing the competition from the HSR entry, airlines may also improve the OTP of the treated flights by rescheduling the treated flights to time slots that are less impacted by air traffic congestion.

In Figure A2 in the Appendix, we plot the average number of schedule flights between January 2009 and December 2012 in 30-minute intervals throughout the day before and after the introduction of the Beijing–Shanghai HSR line on June 30, 2011. It indicates that the number of flights increases in all time slots throughout the day after the HSR entry, which is consistent with the fact that China's commercial aviation industry was in the process of rapid expansion in this period.

To identify the peak and off-peak time slots, we divide the day into 24 slots. In Figure A3 in the Appendix we plot the traffic volume and average departure delay minutes in each of the 24 time slots *before* the introduction of the Beijing–Shanghai HSR line. It shows that the departure flights scheduled for the 1 am, 6 am, 7 am, 9 am, 10 am, 10 pm and 11 pm slots have better OTP prior to the HSR entry. We call these time slots *Better Slots* in terms of OTP of departures.

We then estimate Eq. (2) using a binary variable $\mathit{Better\ Slot}_{i,j,d,t}$ as the dependent variable. $\mathit{Better\ Slot}_{i,j,d,t}$ equals to 1 if the flight was scheduled to depart in one of the better time slots described above, and 0 otherwise. In addition, we also calculate the aggregate fraction of flights in the better time slots at the airline-route-month level and use it as a new dependent variable. Results in Table 13 show that the estimated coefficients on $\mathit{Treatment} \cdot \mathit{After}$ are neither positive nor statistically significant for both the individual flight level analysis and the aggregate airline-route-month level analysis.

[Table 13 About Here]

Outliers. One may also be concerned that our findings may be driven by outliers, for instance, by some flights with extremely long delays. To examine whether the treatment effects are driven by outliers, we also run a series of quantile regressions (Koenker and Hallock, 2001). The estimated coefficients of the interaction term $\mathit{Treatment} \cdot \mathit{After}$ for the nine deciles and the four OTP measures are plotted in Figure 6. We find that all four measures of OTP show significant responses to the HSR entry in all deciles, and that the OTP improvements are more substantial in the upper decile than in the lower quantile, suggesting that flights with the poorest OTP are more responsive to the entry of HSR. This also explains why the HSR entry reduced the variance of the delays as we reported in Section 4.

[Figure 6 About Here]

Air Traffic Control. Finally, one may be concerned that our estimated treatment effects may be driven from the military bases shifting their air traffic control on control routes in the post-HSR period. It is *a prori* quite implausible, but to address it more formally, we use an alternative control group consisting of only international flights, which are mostly exempted from the air traffic control by the Chinese authorities, and are also not subject to the competition from the HSR entry. Table 14 reports the results. It shows that the estimated coefficients for the interaction term *Treatment*After* are qualitatively similar to, and quantitatively even larger than, our baseline results reported in Table 3.

[Table 14 About Here]

5.2 Falsification Tests

As a final verification that our findings are not spurious, we conduct two falsification tests. The first is a placebo test in which we create a *fictitious treatment group* that consist of the nine destination cities linked to the Beijing–Guangzhou HSR line. As discussed above, although these nine cities enter the HSR network after December 26, 2012, none of them was linked to the Beijing–Shanghai HSR line between January 1, 2009 and December 25, 2012. This test addresses whether the difference in the original DID regressions reflects the effect of the HSR competition or the effect of just being chosen as an eventual HSR destination city.

In the second placebo test, we examine whether the original DID effects simply reflect changes in the Chinese airline industry, or the effect of the broader planning and construction of the HSR network. To do this, we create a *fictitious treatment date.* Specifically, we set the introduction of the Beijing–Shanghai HSR line as occurring one year before when it actually occurred, i.e. on June 30, 2010 (instead of the actual date of June 30, 2011). This fictitious treatment date ensures that we still have long pre- and post-period data.

In Tables 15-16, we 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 significant. These findings reinforce our interpretation that our results reported in Table 3 are driven by the treatment flights responding to the competition from the HSR entry, and not spurious.

[Tables 15-16 About Here]

6 The Back-of-the-Envelope Calculation

In this section, we use our estimates to conduct a back-of-the-envelope calculation of a lower bound of the value of the time savings resulting from the improvement in the OTP of the treated flights for air travelers. Following Li et al. (2007) and Yang and Zhang (2012), we consider two types of air travelers, $i = 1$ denotes the business travelers, and $i = 2$ the leisure travelers. We calculate the hourly monetary cost of flight delay for type $i \in \{1, 2\}$, which we denote by V_i, as follows:

$$V_i = \alpha_i * \frac{Wage}{2000}, \tag{5}$$

where $Wage$ denotes the average annual salary and α_i denotes conversion factors for type i traveler relative to the average person in the population. According to the data released by National Bureau of Statistics of China, the average yearly salary in Beijing in 2012 was

CNY 62,676.[18] The denominator, 2000, represents the average total hours worked in a year.[19] Following Li et al. (2007) and Yang and Zhang (2012), we set the conversion factor for business and leisure travelers to be $\alpha_1 = 9$ and $\alpha_2 = 3$, respectively. Thus, the hourly flight delay costs for business and leisure passengers are calculated according to Eq. (5) to be CNY 282 and CNY 94, respectively. Note that, our estimated willingness to pay (WTP) for reductions in flight delay is less than that in Gayle and Yimga (2018), which report that travelers are willing to pay \$1.56 per minute to avoid arrival delays; but they are close to the WTP in Prince and Simon (2015), which show that the WTP for a one-hour reduction in travel time is \$36 and \$15 for business and non-business travelers, respectively.

We next calculate the total monetary cost C for all the passengers on a flight due to an additional minute of delay:

$$C = \sum_{i=1}^{2} N \cdot \beta \cdot \theta_i \cdot \frac{V_i}{60}, \tag{6}$$

where N denotes the total seat count, β denotes the occupancy rate of the flight, and θ_i denotes the share of passenger type i. According to the Civil Aviation Administration, 46% of all airline passengers travel on business and 54% travel on leisure.[20] That is, $\theta_1 = 0.46$ and $\theta_2 = 0.54$. Suppose that each flight has 200 seats on average and an occupancy rate of 80%, then the cost C for all passengers on a flight due to an additional minute of delay is CNY 481.28.

Given that our estimated reduction in the arrival delay for all treated flights before September 2015 is 4.36 minutes (as shown in Column 1 of Table 8), a simple estimate of the value of the time saving per flight from the reduced arrival delay in the post-HSR period is equivalent to CNY 2,098.38 (=4.36*481.28). To obtain a lower bound estimate of the monetary value of the improvement in OTP by treated flights due to the competition from HSR entries, we use all flights along the HSR routes in the post-HSR period for calculation. In our data, 796,191 treated flights fly from Beijing to the 33 HSR destinations between June 30, 2011 and September 30, 2015. Thus on average, there are 187,370 (=796,191/4.25) treated Beijing-outbound flights per year. We assume that Beijing-inbound flights achieve similar improvements in OTP. Moreover, we assume a 5% annual discount rate. A lower bound of the discounted present value of the time saving for air travelers taking round-trip

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

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

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

flights on the affected routes due to the HSR entries is thus given by:

$$\frac{187,370 * 2 * 2,098}{0.05} = CNY15.724\ \textit{Billion}.$$

Notably, this is a lower-bound estimate of the benefits for air travelers on the treated routes because it does not take into account the decrease in airfare caused by the entry of the HSR, or the benefit gained by the travelers who switched from airline to HSR (see Yang and Zhang (2012)); in addition, to the extent that passengers are risk averse to unpredictable flight delays, the reduction in the variance of the flight delays also improves passenger welfare.

7 Conclusion

High-speed railway is one of the major disruptive technologies in transportation in the last twenty years, and the HSR entry has posed fierce competition for passenger air travel, especially short-to-medium-distance travel. In this paper, we use the entry of Beijing-Shanghai HSR as an exogenous increase in competition to affected flights to the destination cities along the HSR line, and investigate whether competition spurs quality improvement, and if so, how.

We first document direct evidence that HSR entry poses a competition shock to airlines in affected routes by showing that the number of flights in the treated routes is reduced in the post-entry period relative to the control routes. We then find that the competition from the HSR entry significantly reduced the departure and arrival delay minutes of the treated flights by an average of 2.54 minutes (about 14.51%) in arrival delay minutes; and at the extensive margin, the HSR entry causes a 2.5% reduction in arrival delays of 15 minutes or longer. We also find that the entry of HSR significantly reduces the variance of flight arrival delay minutes. These results are quantitatively similar when we restrict our control group to Beijing-outbound flights to the nine cities on the Beijing-Guangzhou HSR that opened on December 26, 2012. In addition, decomposing the actual travel time, we find that the decreases in the departure delay and taxi-in runway times are the major sources of the improvement in OTP.

We also evaluate and rule out an exhaustive list of alternative explanations for our findings. The alternative explanations we examined include cancellation of flights on the treated routes with poor OTP, rescheduling treatment flights to better time slots, delays of the incoming flights, among others. We also conduct two falsification tests, one based on a fictitious treatment group and another based on a fictitious treatment date, to rule out that our findings are driven by spurious effects. The results from heterogeneity analysis further reveal that non-hub airlines, i.e. those with less market power, and flights on short-to-medium distance routes, are more responsive to HSR entry in their OTP improvement. Finally, we provide a back-of-the-envelope estimate of the lower bound of the values from the time savings by air travelers due to the improvement of OTP, which amounts to more than 15.7 billion CNY. Our paper thus contributes to the literature on the causal impact of competition on quality, and on the economic benefits of HSR.

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Table 1: Summary Statistics: Flight Level

	Treatment				Control			
	Before		After		Before		After	
	Mean	S.D	Mean	S.D	Mean	S.D	Mean	S.D
ADM	17.32	41.91	17.51	35.99	20.42	40.35	22.64	42.99
ADD15	0.26	0.44	0.28	0.45	0.35	0.48	0.37	0.48
DDM	34.73	44.53	36.5	38.26	32.41	41.48	39.37	46.83
DDD15	0.68	0.47	0.74	0.44	0.66	0.47	0.74	0.44
ATT	129.65	49.09	131.21	43.3	158.17	66.74	166.58	68.51
ETT	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
Schedule 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
Air Time	62.79	23.9	64.35	23.58	93.19	50.65	94.92	51.02
Observations	98,987		107,266		292,818		366,896	

Notes: This table presents the summary statistics of the treatment and control sample in the baseline analysis. The sample includes all Beijing-outbound flights between January 1, 2009 and December 25, 2012. The treatment sample consists of flights departing from Beijing to cities along the Beijing–Shanghai HSR line, and the control sample consists of flights departing from Beijing to other non-HSR cities. The definitions and constructions of the variables are introduced in detail in Section 3.

Table 2: Effect of Competition on the Number of Flights

Dep. Variables	ln(Number of Flights)		
	Flight-Route-Month (1)	Airline-Route-Month (2)	Route-Month (3)
Treatment*After	-0.088*** (0.015)	-0.135*** (0.048)	-0.192** (0.092)
Observations	47,391	15,374	4,751
R-squared	0.512	0.865	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 Equation (1). The sample period is between January 1, 2009 and December 25, 2012. 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 3: Effect of Competition on the On-time performance Measures: Flight Level Results

Dep. Variables	ADM	ADD15	DDM	DDD15	ATT	ETT
Model	(1)	(2)	(3)	(4)	(5)	(6)
Treatment*After	-2.539***	-0.025***	-5.282***	-0.034***	-4.726***	-3.919***
	(0.230)	(0.002)	(0.224)	(0.002)	(0. 236)	(1.240)
Observations	865,967	865,967	865,967	865,967	865,967	865,967
R-squared	0.266	0.196	0.254	0.209	0.636	0.208
Hour FE	Yes	Yes	Yes	Yes	Yes	Yes
Date FE	Yes	Yes	Yes	Yes	Yes	Yes
Flight FE	Yes	Yes	Yes	Yes	Yes	Yes

Notes: This table reports the results of estimating Equation (2). We examine the six measures of OTP: *Arrival Delay in minutes* (ADM), *Arrival Delay 15 minutes* (ADD15), *Departure Delay in minutes* (DDM), *Departure Delay 15 minutes* (DDD15), actual travel time (ATT), and excessive travel time (ETT). The sample period is from January 1, 2009 to December 25, 2012. The hour, date, and flight fixed effects are included in all specifications. Standard errors clustered by destinations are reported in parentheses. We use ***, **, and * to denote significance at the 1%, 5%, and 10% levels, respectively.

Table 4: Effect of Competition on the Variance of On-time Performance: Flight-Weekly Level Results

Dep. Variables	Var. of ADM	Var. of DDM	Var. of ATT	Var. of ETT
	(1)	(2)	(3)	(4)
Treatment*After	-475.113***	-487.390***	-509.221***	-507.734***
	(58.658)	(59.993)	(70.310)	(70.426)
Observations	150,019	150,019	150,019	150,019
R-squared	0.100	0.117	0.049	0.049
Year-Week FE	Yes	Yes	Yes	Yes
Flight FE	Yes	Yes	Yes	Yes

Notes: This table reports the results of variance analysis. The dependent variable is the weekly variance of OTP measures. The sample period is from January 1, 2009 to December 25, 2012. The year-week and flight fixed effects are included in all specifications. Standard errors clustered by destinations are reported in parentheses. We use ***, **, and * to denote significance at the 1%, 5%, and 10% levels, respectively.

Table 5: Effect of Competition on the On-Time Performance Measures: Airline-Route-Month Level Results

Dep. Variables	ADM	ADR15	DDM	DDR15	ATT	ETT
	(1)	(2)	(3)	(4)	(5)	(6)
Treatment*After	-3.419**	-0.028***	-5.445***	-0.043**	-5.300***	-4.628***
	(1.441)	(0.011)	(1.723)	(0.021)	(1.217)	(1.195)
Observations	12,499	12,499	12,499	12,499	12,499	12,499
R-squared	0.610	0.640	0.613	0.640	0.958	0.530
Year-Month FE	Yes	Yes	Yes	Yes	Yes	Yes
Airline FE	Yes	Yes	Yes	Yes	Yes	Yes
Route FE	Yes	Yes	Yes	Yes	Yes	Yes

Notes: This table reports the results of estimating the WLS models based on Equation (4), weighting each observation by the number of flights in each cell. We examine the six measures of OTP at the airline-route-month level. The sample period is from January 1, 2009 to December 25, 2012. The year-month, airline, and route fixed effects are included in all specifications. Standard errors clustered by destinations are reported in parentheses. We use ***, **, and * to denote significance at the 1%, 5%, and 10% levels, respectively.

Table 6: Effect of Competition on the On-time Performance Measures: Beijing–Shanghai HSR (Treatment) vs. Beijing–Guangzhou HSR (Control)

Dep. Variables	ADM	ADD15	DDM	DDD15	ATT	ETT
	(1)	(2)	(3)	(4)	(5)	(6)
Treatment*After	-2.241***	-0.035***	-2.991***	-0.030***	-3.587***	-2.345***
	(0.284)	(0.003)	(0.277)	(0.011)	(0.285)	(0.283)
Observations	400,158	400,158	400,158	400,158	400,158	400,158
R-squared	0.296	0.212	0.274	0.213	0.577	0.238
Hour FE	Yes	Yes	Yes	Yes	Yes	Yes
Date FE	Yes	Yes	Yes	Yes	Yes	Yes
Flight FE	Yes	Yes	Yes	Yes	Yes	Yes

Notes: This table reports the results of estimating the HSR competition effects in the subsample. The sample period is from January 1, 2009 to December 25, 2012. The treatment group includes flights departing from Beijing to the 11 destinations linked to the Beijing–Shanghai HSR line. The control group includes flights departing from Beijing to the 9 destinations that would later be linked to the Beijing–Guangzhou HSR line after December 26, 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 7: Sources of Quality Improvement from Competition: Flight Level Results

			Components of Actual Duration			
Dep. Variables	Departure Delay	Actual Duration	Taxi-out	Taxi-in	Air time	Scheduled Duration
Model	(1)	(2)	(3)	(4)	(5)	(6)
Treatment*After	-5.282***	0.391	0.117	-1.389***	1.740***	0.819
	(0.224)	(0.541)	(0.086)	(0.055)	(0.124)	(0.941)
Observations	865,967	865,967	865,387	865,387	865,387	865,967
R-squared	0.254	0.929	0.097	0.141	0.813	0.976
Hour FE	Yes	Yes	Yes	Yes	Yes	Yes
Date FE	Yes	Yes	Yes	Yes	Yes	Yes
Flight FE	Yes	Yes	Yes	Yes	Yes	Yes

Notes: This table reports the results of estimating the effects of the HSR introduction on the *departure delay, actual duration,* and *scheduled duration. Actual Duration* is divided into *taxi-out time* (Column 3), *taxi-in time* (Column 4) and *air time* (Column 5). The sample period is from January 1, 2009 to December 25, 2012. The hour, date, and flight fixed effects are included in the individual regressions. 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: Effect of Competition on the On-Time Performance Measures: All HSR Entries up to September 2015

Dep. Variables	ADM	ADD15	DDM	DDD15	ATT	ETT
	(1)	(2)	(3)	(4)	(5)	(6)
Treatment*After	-4.357***	-0.024***	-3.553***	-0.039***	-2.455***	-2.154***
	(0.274)	(0.001)	(0.116)	(0.001)	(0.130)	(0.128)
Observations	2,001,362	2,001,362	2,001,362	2,001,362	2,001,362	2,001,362
R-squared	0.231	0.196	0.246	0.220	0.564	0.197
Hour FE	Yes	Yes	Yes	Yes	Yes	Yes
Date FE	Yes	Yes	Yes	Yes	Yes	Yes
Flight FE	Yes	Yes	Yes	Yes	Yes	Yes

Notes: This table reports the results of estimating the HSR competition effects in an extended sample. The sample period is from January 2009 to September 2015. The number of treated destinations increased from 11 to 33 in September 2015. The 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 9: Heterogeneous Effects of the Competition on the On-Time Performance Measures: Flight Level Results

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

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

Table 10: Subsample Analysis: Only Flights in the Holiday Periods

Dep. Variables	ADM	ADD15	DDM	DDD15	ATT	ETT
	(1)	(2)	(3)	(4)	(5)	(6)
Treatment*After	-1.628**	-0.017**	-2.505***	-0.024**	-3.558***	-2.001**
	(0.798)	(0.008)	(0.781)	(0.011)	(0.838)	(0.826)
Observations	54,719	54,719	54,719	54,719	54,719	54,719
R-squared	0.266	0.204	0.239	0.220	0.700	0.202
Hour FE	Yes	Yes	Yes	Yes	Yes	Yes
Date FE	Yes	Yes	Yes	Yes	Yes	Yes
Flight FE	Yes	Yes	Yes	Yes	Yes	Yes

Notes: This table reports the results of estimating Equation (2) 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. The sample period is from January 1, 2009 to December 25, 2012. The hour, date, and flight fixed effects are included in all specifications. Standard errors clustered by destinations are reported in parentheses. We use ***, **, and * to denote significance at the 1%, 5%, and 10% levels, respectively.

Table 11: Subsample Analysis: Only Flights that Operated Both Before and After the HSR Entry

Dep. Variables	ADM	ADD15	DDM	DDD15	ATT	ETT
	(1)	(2)	(3)	(4)	(5)	(6)
Treatment*After	-2.579***	-0.026***	-5.374***	-0.035***	-4.717***	-3.975***
	(0.230)	(0.003)	(0.229)	(0.003)	(0.234)	(0.362)
Observations	716,304	716,304	716,304	716,304	716,304	716,304
R-squared	0.262	0.193	0.253	0.206	0.637	0.237
Hour FE	Yes	Yes	Yes	Yes	Yes	Yes
Date FE	Yes	Yes	Yes	Yes	Yes	Yes
Flight FE	Yes	Yes	Yes	Yes	Yes	Yes

Notes: This table includes flights that existed both before and after the introduction of the Beijing–Shanghai HSR line. 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 12: Subsample Analysis: Only Morning Flights Between 6 am and 9 am

Dep. Variables	ADM	ADD15	DDM	DDD15	ATT	ETT
	(1)	(2)	(3)	(4)	(5)	(6)
Treatment*After	-2.057***	-0.019***	-2.717***	-0.023***	-2.992***	-1.993***
	(0.419)	(0.004)	(0.401)	(0.005)	(0.425)	(0.417)
Observations	216,840	216,840	216,840	216,840	216,840	216,840
R-squared	0.318	0.246	0.330	0.257	0.692	0.268
Hour FE	Yes	Yes	Yes	Yes	Yes	Yes
Date FE	Yes	Yes	Yes	Yes	Yes	Yes
Flight FE	Yes	Yes	Yes	Yes	Yes	Yes

Notes: This table focuses on a subsample consisting only of flights departing in the early morning (6am to 9am). The hour, date and flight fixed effects are included 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: DID Tests on the Probability of Schedule Reshuffling

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

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

Table 14: Effect of Competition on the On-Time Performance Measures: International Flights as the Control Flights

Dep. Variables	ADM	ADD15	DDM	DDD15	ATT	ETT
	(1)	(2)	(3)	(4)	(5)	(6)
Treatment*After	-2.215***	-0.026***	-2.141***	-0.036***	-2.606***	-2.684***
	(0.363)	(0.003)	(0.384)	(0.003)	(0.655)	(0.867)
Observations	342,175	342,175	342,175	342,175	342,175	342,175
R-squared	0.290	0.208	0.259	0.277	0.869	0.326
Hour FE	Yes	Yes	Yes	Yes	Yes	Yes
Date FE	Yes	Yes	Yes	Yes	Yes	Yes
Flight FE	Yes	Yes	Yes	Yes	Yes	Yes

Notes: This table reports the results of estimating the effect of the HSR introduction on departure delays with the control group consisting only of international flights. The 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 15: Placebo Tests: Fictitious Treatment Group

Dep. Variables	ADM	ADR15	DDM	DDR15	ATT	ETT
	(1)	(2)	(3)	(4)	(5)	(6)
Treatment*After	0.416	-0.006	-2.102	0.001	0.046	-0.593
	(1.619)	(0.013)	(1.320)	(0.016)	(1.219)	(1.048)
Observations	10,203	10,203	10,203	10,203	10,203	10,203
R-squared	0.509	0.553	0.529	0.652	0.936	0.382
Year-Month FE	Yes	Yes	Yes	Yes	Yes	Yes
Airline FE	Yes	Yes	Yes	Yes	Yes	Yes
Route FE	Yes	Yes	Yes	Yes	Yes	Yes

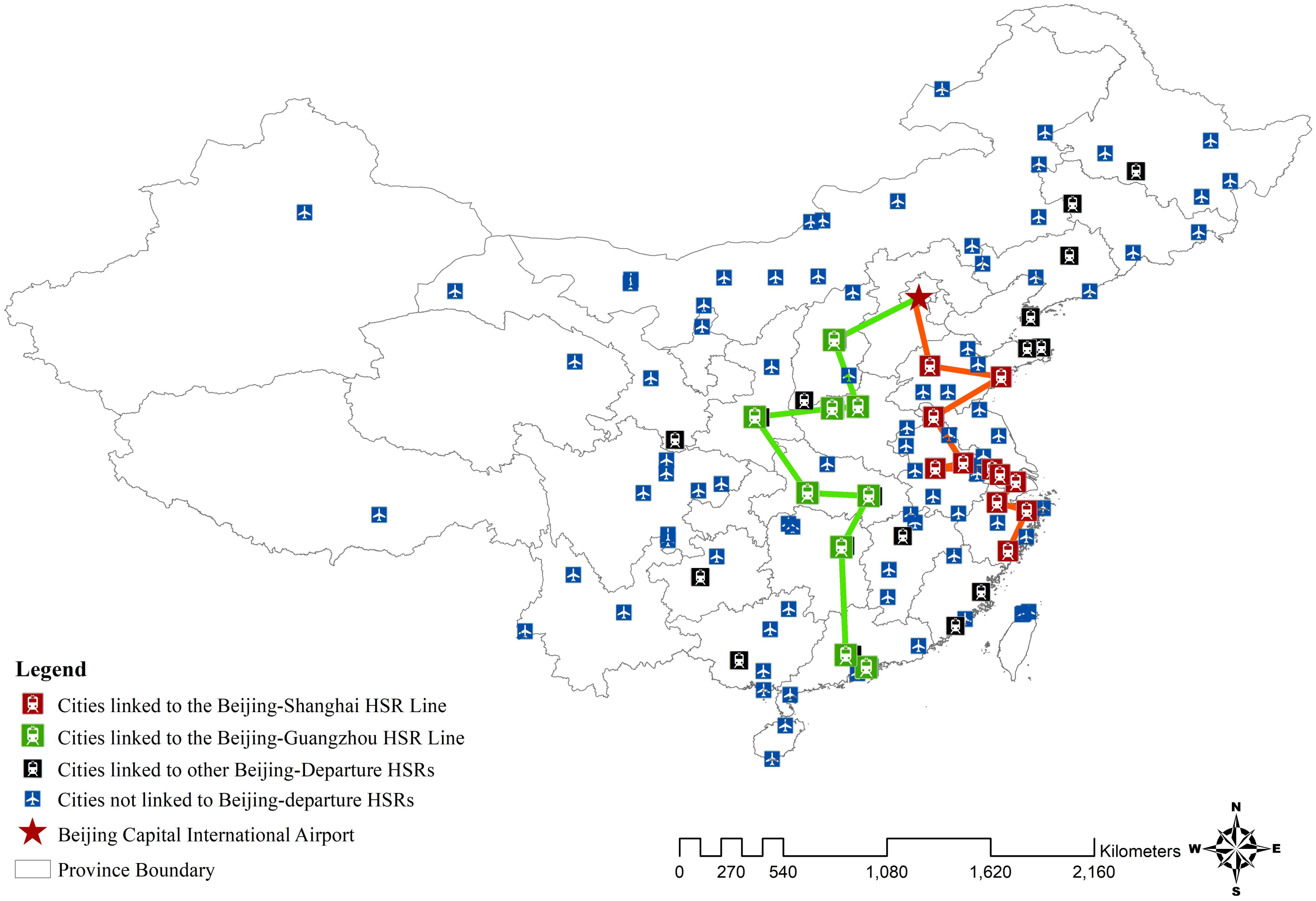
Notes: This table reports the results of a placebo test by creating a fictitious treatment group consisting of nine destinations linked to the Beijing–Guangzhou HSR line after December 26, 2012. The destinations in the fictitious treatment group were not linked to the Beijing–Shanghai HSR line between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

Table 16: Placebo Tests: Fictitious Treatment Date

Dep. Variables	ADM	ADR15	DDM	DDR15	ATT	ETT
	(1)	(2)	(3)	(4)	(5)	(6)
Treatment*After	2.366	0.008	1.011	0.017	1.420	0.086
	(1.985)	(0.009)	(1.752)	(0.017)	(1.587)	(1.145)
Observations	6,129	6,129	6,158	6,129	6,129	6,129
R-squared	0.498	0.606	0.540	0.655	0.921	0.384
Year-Month FE	Yes	Yes	Yes	Yes	Yes	Yes
Airline FE	Yes	Yes	Yes	Yes	Yes	Yes
Route FE	Yes	Yes	Yes	Yes	Yes	Yes

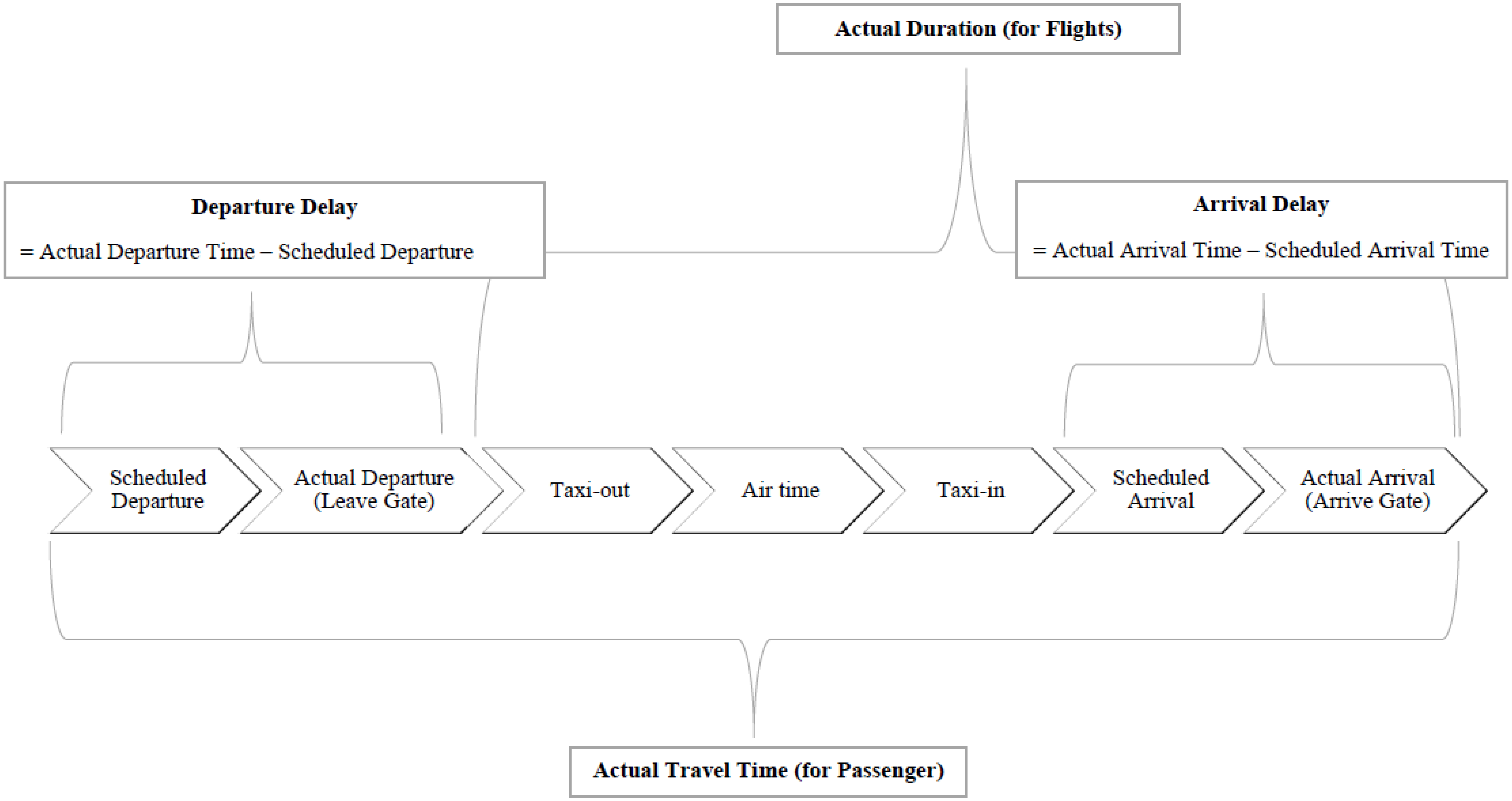
Notes: This table tests a fictitious treatment date, which is placed at a point (e.g., on June 30, 2010) one year before the introduction (e.g., on June 30, 2011) of the Beijing–Shanghai HSR line. The year-month, airline, and route fixed effects are included in the aggregate level analysis. Standard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

Figure 1: Geographic Distribution of Sample Cities in September 2015



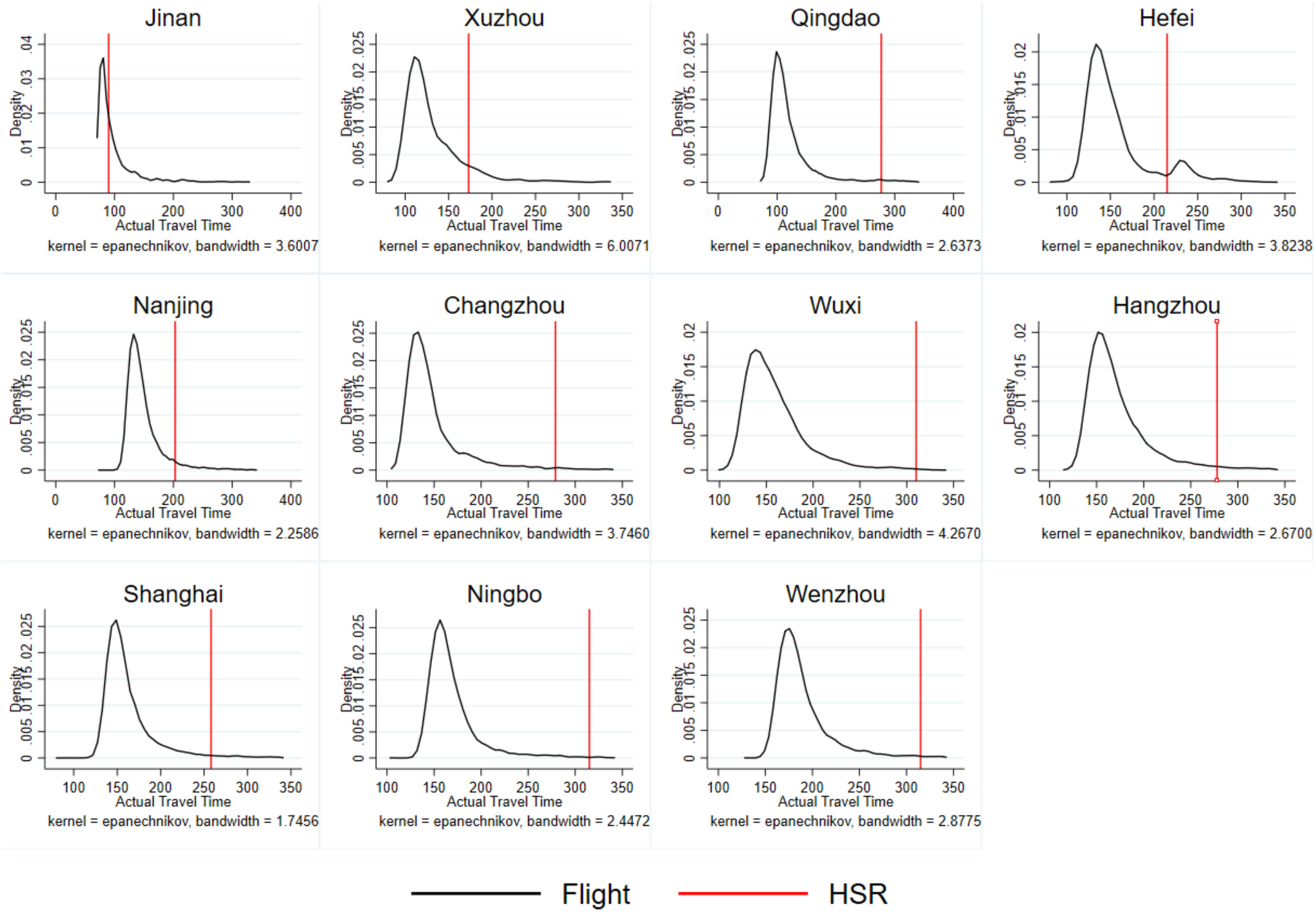
Notes: This figure presents the geographic distribution of the sample destinations in September 2015. The red train signs denote the 11 treated destinations linked to the Beijing–Shanghai HSR line introduced on June 30, 2011. The green train signs denote the nine destinations linked to the Beijing–Guangzhou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

Figure 2: Flowchart for Flight Delays



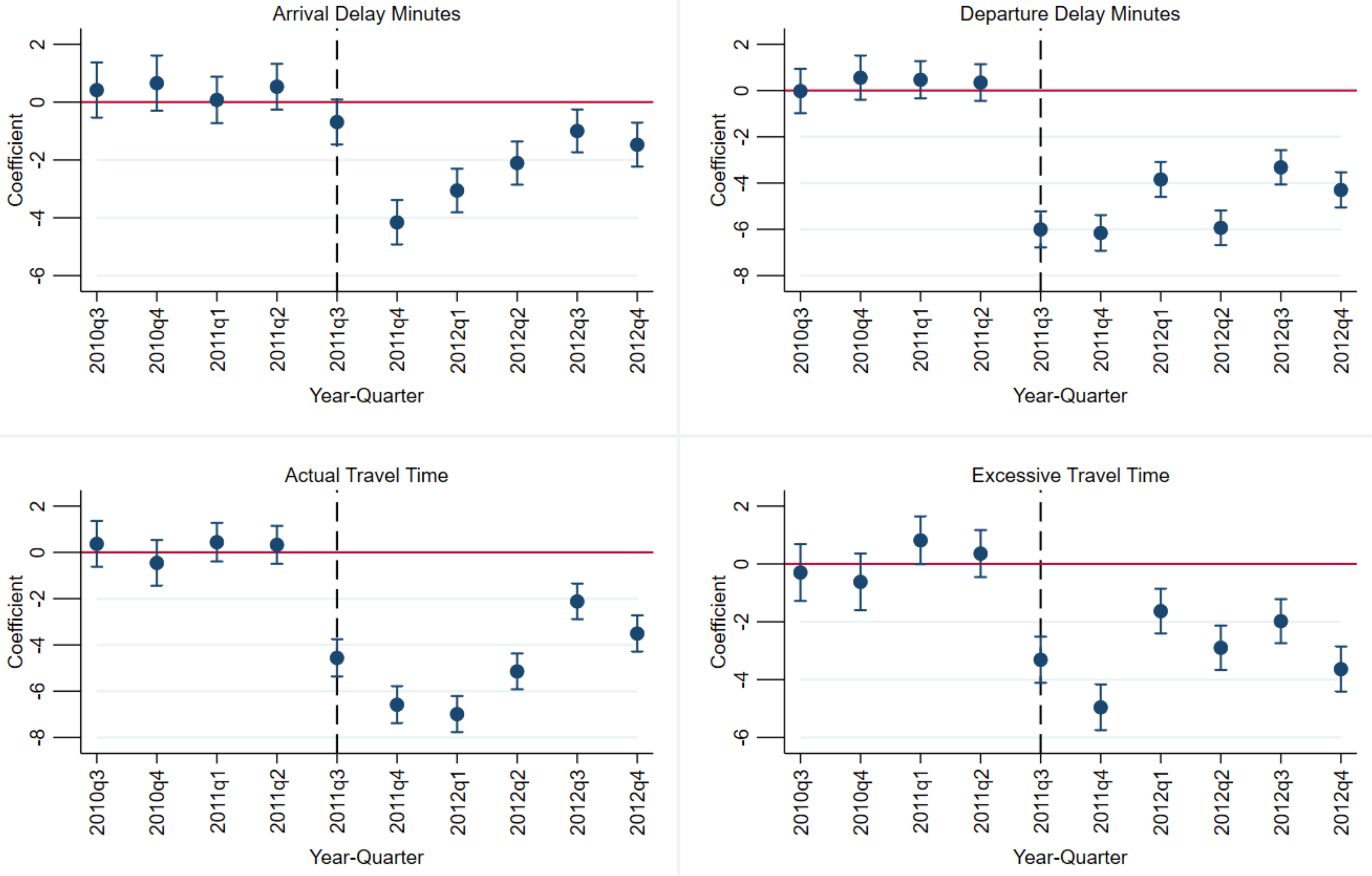
Notes: The flowchart illustrates the components of the flight departure and arrival delays. *Actual Travel Time* (ATT) captures the time difference between the *scheduled departure time* and *actual arrival time.* The *departure delay* is calculated as the time spent before leaving the gate (the difference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

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



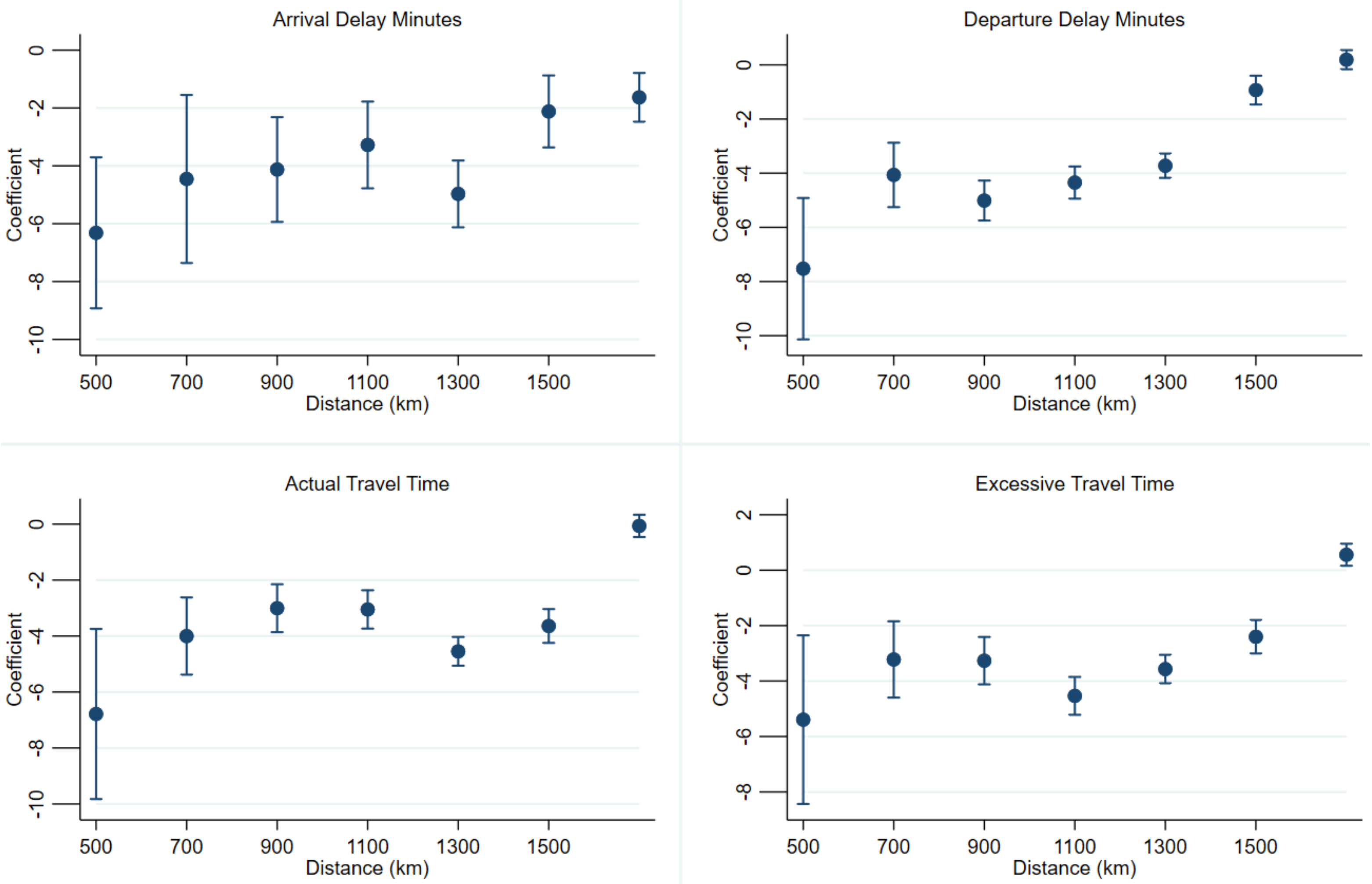
Notes: This figure shows the distributions of actual travel time (the difference between the actual arrival time minus the scheduled departure time) for the flights linking Beijing and the 11 HSR destinations along the Beijing-Shanghai line (in black). The fastest scheduled travel time for the corresponding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

Figure 4: Dynamic Changes of the Four OTP Measures



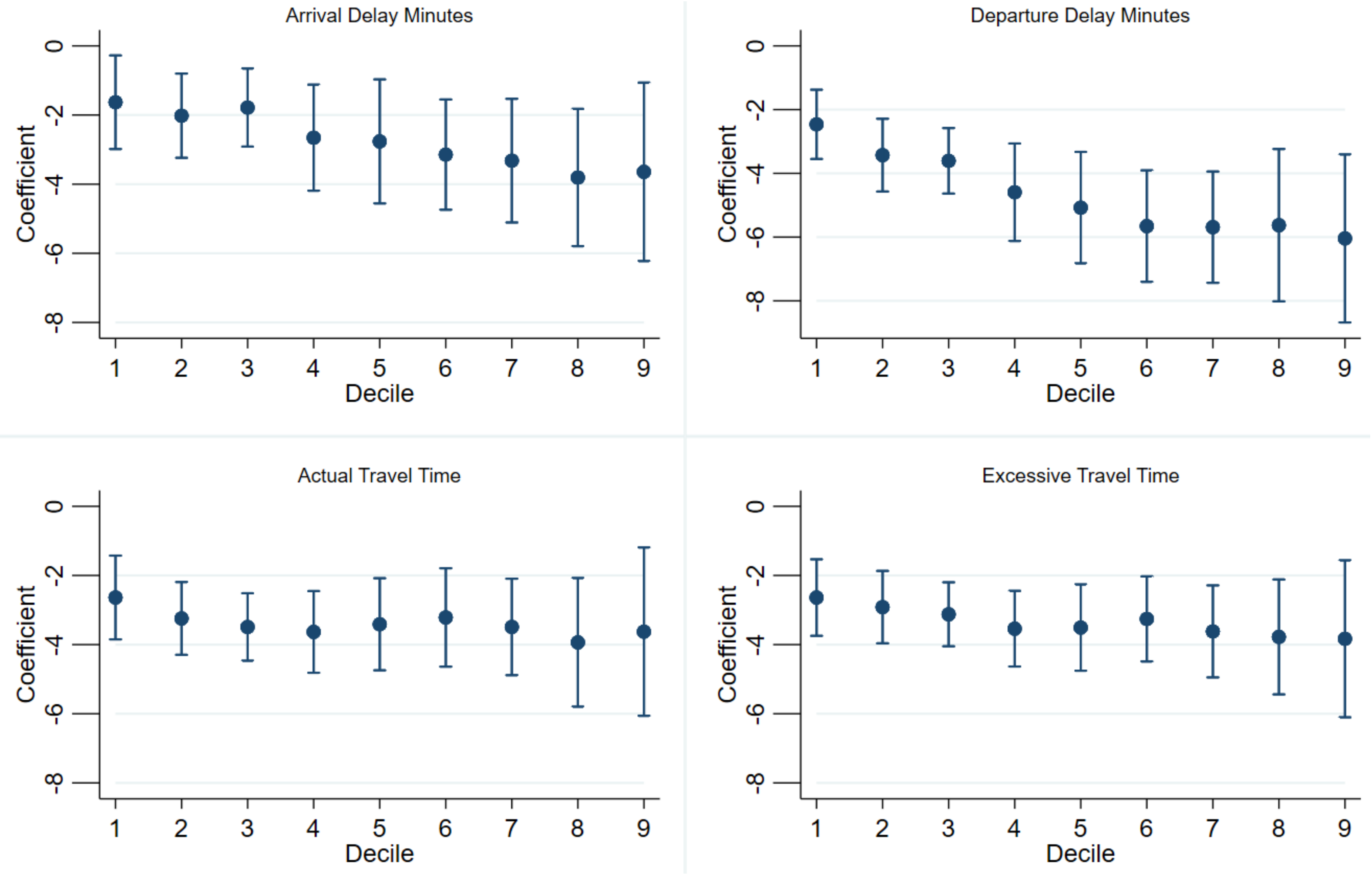
Notes: This figure plots the dynamic responses of the four OTP measures to the introduction of the Beijing–Shanghai HSR line. The coefficients and 95% confidence intervals are obtained from estimating Equation (3).

Figure 5: Heterogeneity in Distance



Notes: This figure plots the heterogeneity responses of four OTP measures to the introduction of the Beijing–Shanghai HSR line across different distance categories. The travel distances range from 500 km to over 1,500 km with a 200 km interval. We plot the 95% confidence intervals.

Figure 6: Quantile Estimations



Notes: This figure plots the estimates of treatment effect using the quantile regressions (i.e., at quantiles 10% (decile 1), 20% (decile 2), . . . , and 90% (decile 9)). Standard errors are obtained by bootstrapping using 500 repetitions each time. We plot the 95% confidence intervals.

Table A1: HSR cities Linked to Beijing

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

Table A1 Continues

Zhengzhou	Henan	3hour25minute	693km	2012-12-26	Beijing-Guangzhou (Beijing-Zhengzhou Section)
Luoyang	Henan	5hour17minute	832km	2012-12-26	Beijing-Guangzhou (Beijing-Zhengzhou Section)
Xian	Sanxi	5hour51minute	1212km	2012-12-26	Beijing-Guangzhou (Beijing-Zhengzhou Section)
Wuhan	Hubei	5hour40minute	1229km	2012-12-26	Beijing-Guangzhou (Beijing-Zhengzhou Section)
Huanggang	Hubei	5hour47minute	1294km	2012-12-26	Beijing-Guangzhou (Beijing-Zhengzhou Section)
Yichang	Hubei	6hour18minute	1525km	2012-12-26	Beijing-Guangzhou (Beijing-Zhengzhou Section)
Changsha	Hunan	5hour42minute	1631km	2012-12-26	Beijing-Guangzhou (Beijing-Zhengzhou Section)
Guangzhou	Guangdong	9hour21minute	2298km	2012-12-26	Beijing-Guangzhou (Beijing-Zhengzhou Section)
Shenzhen	Guangdong	10hour36minute	2409km	2012-12-26	Beijing-Guangzhou (Beijing-Zhengzhou Section)
Tangshan	Hebei	1hour29minute	241km	2013-12-31	Tianjin-Qinhuangdao
Qinhuangdao	Hebei	2hour1minute	388km	2013-12-31	Tianjin-Qinhuangdao
Shenyang	Liaoning	3hour58minute	786km	2013-12-31	Tianjin-Qinhuangdao
Dalian	Liaoning	4hour52minute	963km	2013-12-31	Tianjin-Qinhuangdao
Changchun	Jilin	6hour19minute	1103km	2013-12-31	Tianjin-Qinhuangdao
Jilin	Jilin	5hour57minute	1214km	2013-12-31	Tianjin-Qinhuangdao
Harbin	Heilongjiang	7hour16minute	1331km	2013-12-31	Tianjin-Qinhuangdao
Baoji	Sanxi	7hour16minute	1379km	2013-12-31	Xuzhou-Lanzhou (Xi'an-Baoji Section)
Fuzhou	Fujian	9hour14minute	1808km	2013-7-1	Hangzhou-Shenzhen (Hangzhou-Ningbo Section)
Quanzhou	Fujian	10hour55minute	1963km	2013-7-1	Hangzhou-Shenzhen (Hangzhou-Ningbo Section)
Yantai	Shandong	7hour16minute	961km	2014-12-28	Qingdao-Rongcheng (Jimo-Rongcheng Section)
Weihai	Shandong	7hour20minute	1063km	2014-12-28	Qingdao-Rongcheng (Jimo-Rongcheng Section)
Yuncheng	Shanxi	6hour12minute	922km	2014-7-1	Datong-Xi'an (Taiyuan-Xi'an Section)
Xiamen	Fujian	10hour55minute	2053km	2014-7-1	Hangzhou-Shenzhen (Hangzhou-Ningbo Section)
Nanchang	Jiangxi	9hour4minute	1933km	2014-9-16	Shanghai-Kunming (Nanchang-Changsha Section)
Nanning	Guangxi	13hour58minute	2478km	2014-9-25	Liuzhou-Nanning
Chongqing	Chongqing	12hour11minute	2078km	2015-1-1	Chongqing-Wuhan
Anqing	Anhui	7hour4minute	1257km	2015-12-6	Ningbo-Anqing
Huangshan	Anhui	6hour29minute	1306km	2015-7-1	Hefei-Fuzhou
Guiyang	Guizhou	10hour47minute	2297km	2015-7-1	Shanghai-Kunming (Xinhuang-Guiyang Section)

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

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

	Treatment				Control			
	Before		After		Before		After	
	Mean	S.D	Mean	S.D	Mean	S.D	Mean	S.D
ADM	18.31	15.46	17.08	13.43	20.57	16.93	20.99	15.27
ADD15	0.14	0.15	0.21	0.17	0.18	0.2	0.29	0.21
DDM	34.31	16.46	36.16	14.07	31.83	17.51	38.03	18.49
DDD15	0.36	0.3	0.62	0.24	0.35	0.31	0.65	0.23
Travel Time	129.05	26.62	128.84	24.92	154.34	51.39	160.63	52.48
Excessive Travel Time	31.78	14.48	31.77	12.96	31.66	16.91	34.69	15.18
Actual Duration	102.36	22.1	99.12	21.06	128.62	48.35	126.64	48.41
Schedule 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
Air Time	63.81	19.4	65.59	20.09	90.47	45.61	92.55	46.76
Observations	1,164		1,132		4,965		5,238	

Notes: This table presents the airline-route-month level summary statistics of the treatment and control sample in the baseline analysis. The sample includes all Beijing-outbound flights between January 1, 2009 and December 25, 2012. The definitions and constructions of the variables are introduced in detail in Section 3.

Table A3: Flight Level DID - Arrival Delays with Airline and Route Level shocks

Panel A. Including Airline-Year-Month Fixed Effects

Dep. Variables	ADM	ADD15	DDM15	DDD15	ATT	ETT
	(1)	(2)	(3)	(4)	(5)	(6)
Treatment*After	-2.805***	-0.018***	-6.025***	-0.028***	-4.828***	-3.925***
	(0.242)	(0.003)	(0.240)	(0.003)	(0.248)	(0.246)
Observations	865,967	865,967	865,967	865,967	865,967	865,046
R-squared	0.272	0.230	0.266	0.209	0.639	0.213
Fixed Effects	Hour FE, Date FE, Flight FE, Airline-Year-Month FE					

Panel B. Including Route-Year-Month Fixed Effects

Treatment*After	-3.414***	-0.024***	-5.384***	-0.025***	-5.220***	-4.201***
	(0.243)	(0.003)	(0.241)	(0.003)	(0.248)	(0.248)
Observations	865,967	865,967	865,967	865,967	865,967	865,051
R-squared	0.275	0.235	0.266	0.204	0.645	0.216
Fixed Effects	Hour FE, Date FE, Flight FE, Route-Year-Month FE					

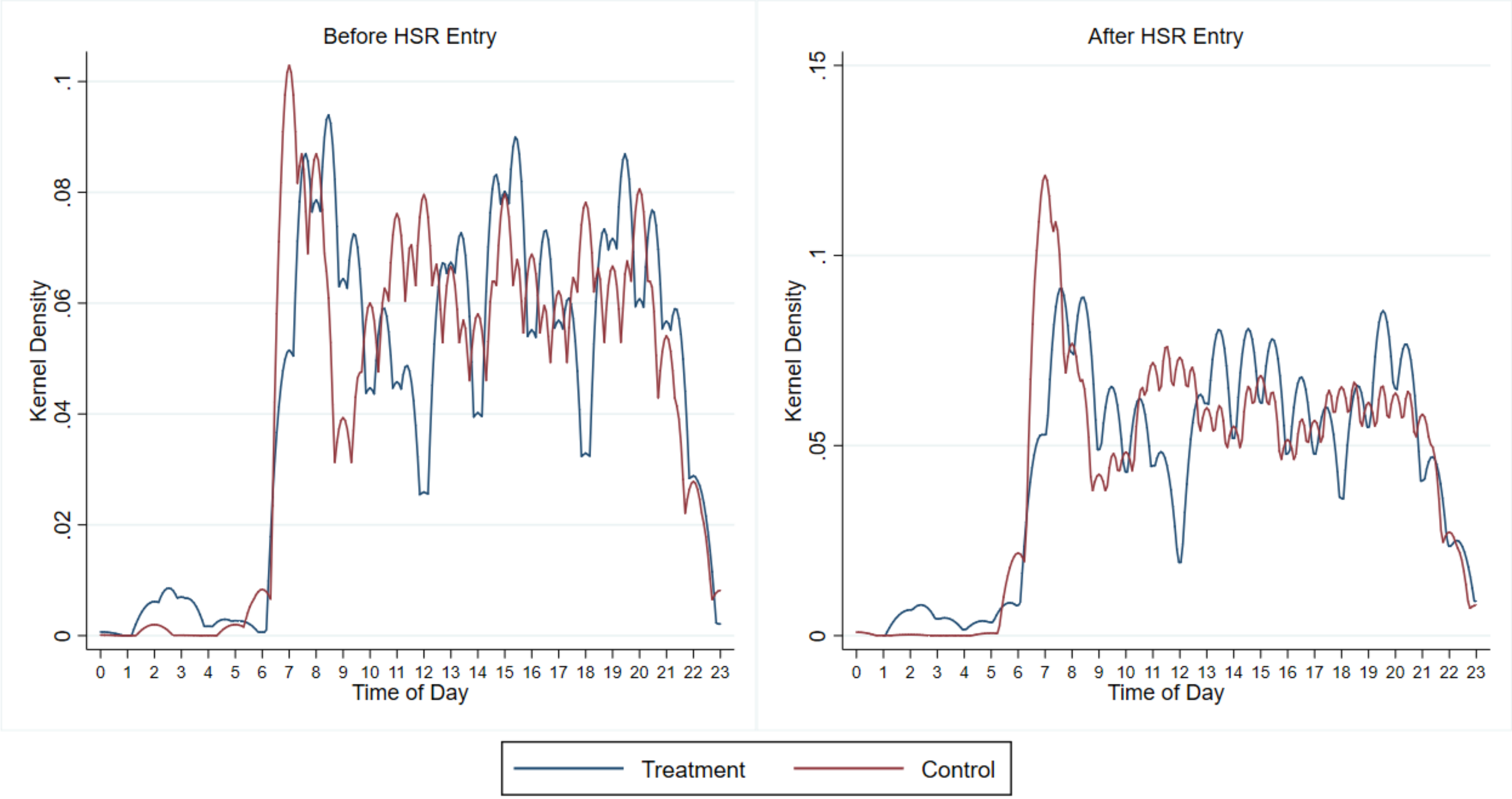
Notes: This table reports the results of estimating Equation (2). The sample period is from January 1, 2009 to December 25, 2012. The hour, date, and flight fixed effects are included in all specifications. The airline dummy interacted with the year-month dummy is included in Panel A, and the route dummy interacted with the year-month dummy is included 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 A4: Comparison of the Treatment and Control Groups before the Introduction of the Beijing–Shanghai HSR Line

	Treat		Control1		Control2		Treat-Control1	Treat-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
DDM	32.90	8.30	35.25	11.63	33.94	8.40	-2.35**	-1.04
ADM	16.92	11.55	19.30	15.40	18.19	10.49	-2.38***	-1.27*
ATT	123.29	25.67	146.85	48.59	144.54	44.54	-23.56***	-21.25**
ETT	32.37	6.82	33.41	10.35	33.47	5.67	-1.04	-1.10

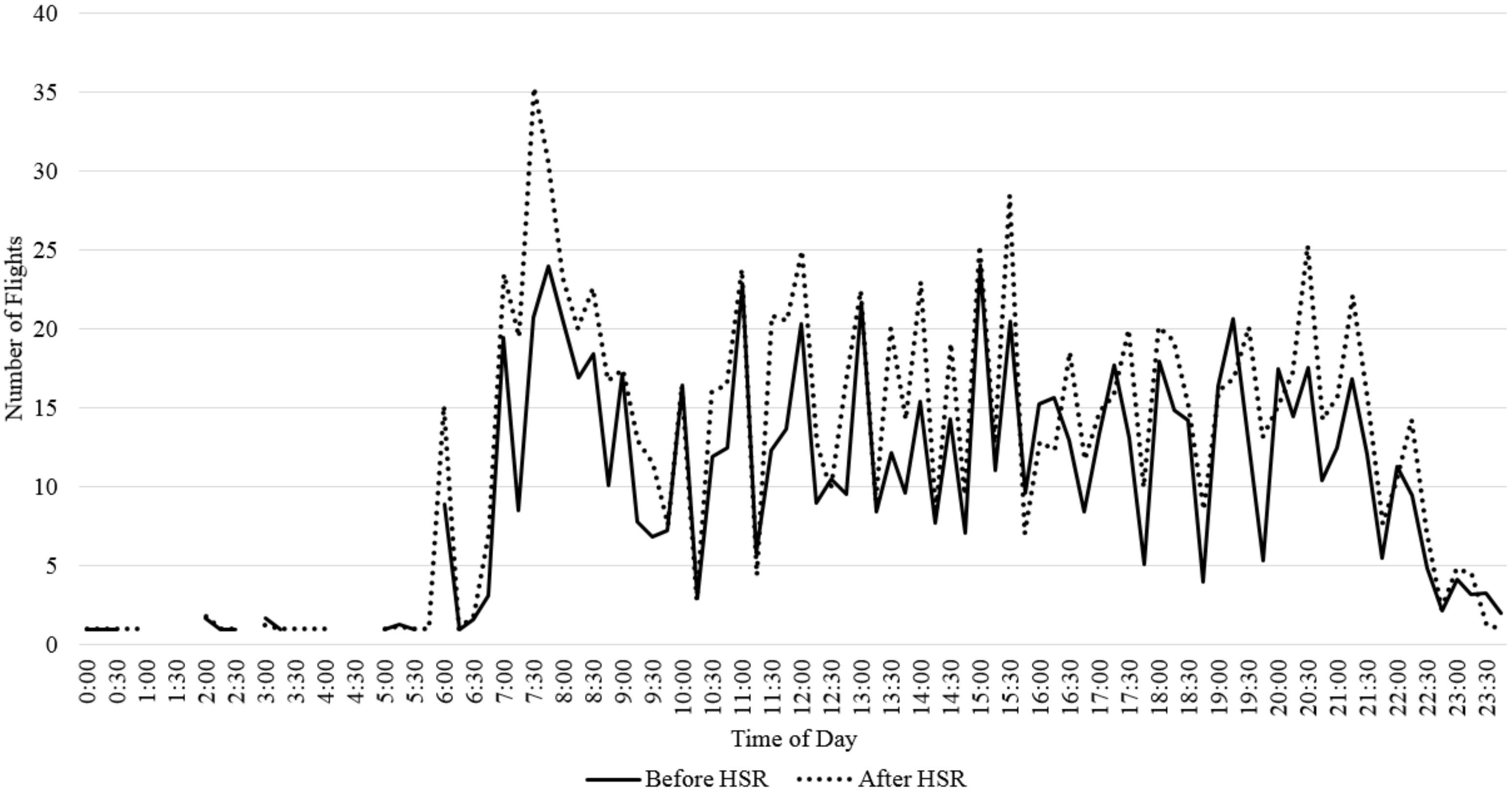
Notes: This table reports the difference between the treatment and control destination cities in the key economic variables and four OTP measures. *Treat* refers to flights departing from Beijing to 11 destination cities linked to the Beijing–Shanghai HSR line. *Control 1* refers to flights departing from Beijing to 102 destination cities not linked to the Beijing–Shanghai HSR line. *Control 2* refers to flights departing from Beijing to nine destination cities later linked to the Beijing–Guangzhou HSR line.

Figure A1: Distribution of Flights throughout the Day



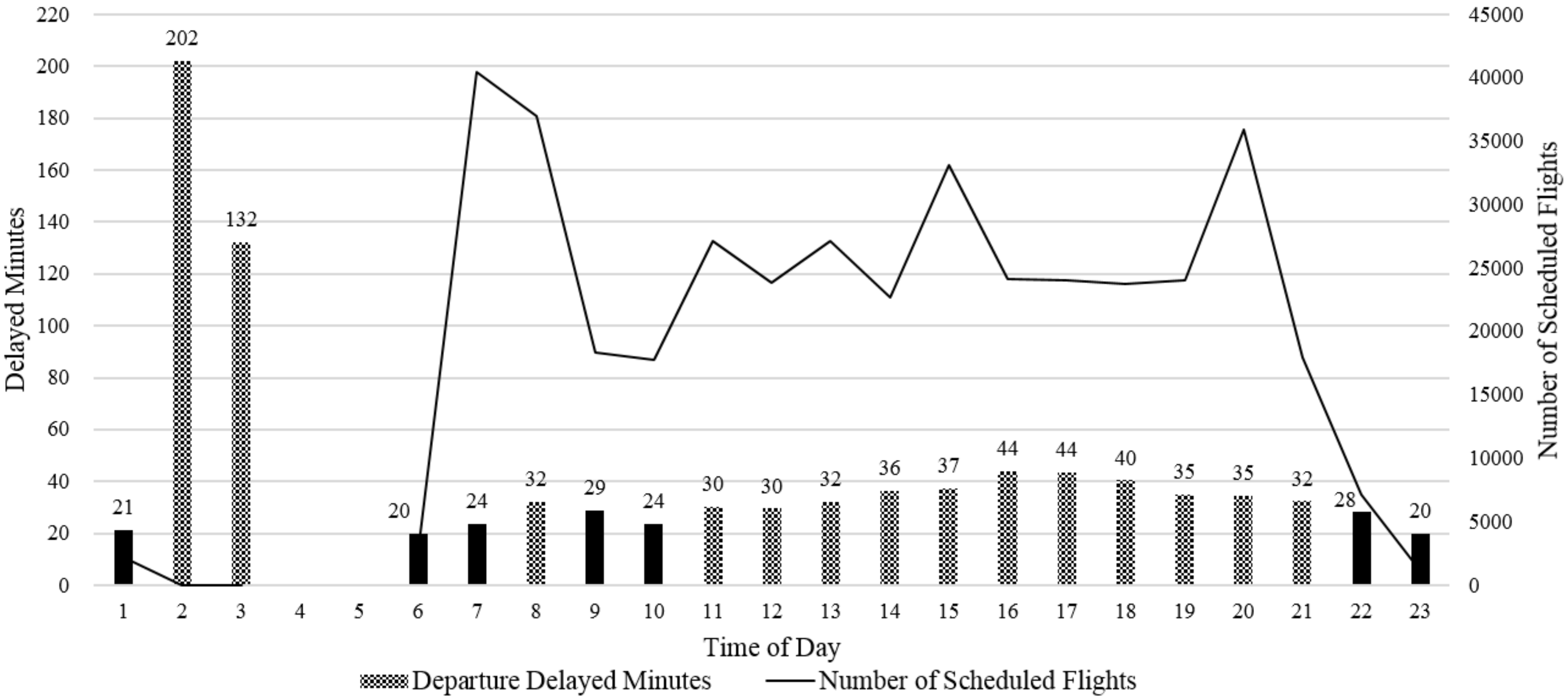
Notes: This figure plots the distribution of flights in the treatment (blue line) and control (red line) groups per hour.

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



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

Figure A3: Distribution of the Departure Delay in Minutes throughout the Day



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