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High-speed railway and the intercity transmission of epidemics: Evidence from COVID-19 in China

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ABSTRACT

In the context of the COVID-19 outbreak in Wuhan, we investigate the effect of intercity high-speed railway (HSR) connections on intercity transmission of epidemics in the absence of government intervention. Intercity HSR connections increase the number of COVID-19 patients per 10,000 population by 0.029, accounting for 45% of the total infections. Our results remain intact in several robustness assessments. The total economic loss owing to HSR connections to Wuhan is estimated to be USD 0.62 billion. The internal mechanism demonstrates that intercity HSR connections increase intercity COVID-19 transmission by facilitating human mobility between cities. Based on intercity transportation connections, our findings can help the government predict the direction and scope of virus transmission and control the intercity transmission of epidemics.

1. Introduction

At the end of 2019, Wuhan was the first major city in China to be affected by COVID-19. To prevent the spread of COVID-19, the Wuhan government implemented traffic control policies that prohibited travel to and from Wuhan on January 23, 2020. Fang et al. (2020) found that Wuhan's lockdown policy significantly reduced COVID-19 transmission. However, there are few studies that focused on the intercity transmission of COVID-19 before Wuhan's lockdown policy. When an epidemic breaks out, studying the transmission of epidemics (COVID-19) under lenient prevention and control conditions (without government intervention) allows the government to predict the direction and scope of virus transmission in a more forward-looking and precise manner. Furthermore, the expansion of transportation is strongly linked to the spread of viruses (Adda, 2016). Therefore, in the context of the COVID-19 outbreak in Wuhan, we investigate the effect of intercity high-speed railway (HSR) connections on intercity transmission of epidemics in the absence of government intervention and the economic loss owing to HSR connections to Wuhan during the early stages of the COVID-19 outbreak.

We primarily emphasize China's HSR in our investigation based on two key considerations. First, in China, the capacity of HSR in transporting passengers is significantly larger than that of airline and waterway transportation. Therefore, HSR connections are likely to have a significant impact on intercity COVID-19 transmission in China as HSR can quickly transmit COVID-19 infections from one city (Wuhan) to other cities and even spread the infection to other passengers in a relatively confined space, such as the HSR car through close contact.

2. Related literature

According to the latest version of the Novel Coronavirus Pneumonia Diagnosis and Treatment Plan issued by the National Health Commission of China, respiratory droplets and close contact are the main routes of COVID-19 transmission. For instance, Lin (2017) finds that HSR connections promote city-wide passenger flows by 10% and employment by 7%. Moreover, Shao et al. (2017) find that HSR positively affects the urban service industry agglomeration of the cities located along the railway lines. Meanwhile, Dong et al. (2020) highlight the role of HSR in the intercity knowledge creation of high skilled workers.
To eliminate the impact of other means of transportation (highway, waterway, and airline) on the baseline results as much as possible, we include annual highway, waterway, and airline passenger; freight transport volume; number of people employed in transportation; storage; and postal service industries as control variables when investigating the causal effect of intercity HSR connections on intercity transmission of COVID-19. In addition, to rule out the possible unobservable factors, such as potential cultural and geographical connections between Wuhan and other cities, we collect data on the cultural connections measured by different dialects (Liu et al., 2015) and geographical distance between Wuhan and other cities. Furthermore, we employ the instrumental variable (IV) method using the least cost routing approach similar to the one adopted by Faber (2014) to verify the reliability of the baseline results of our study.

According to the empirical findings, intercity HSR connections increase the number of COVID-19 patients per 10,000 population by 0.029, accounting for 45% of the total infections. Subsequently, we rule out some possible interference owing to measurement errors in the dependent variable, omitted variables and national HSR network effect. The heterogeneity analysis demonstrates that being connected to Wuhan via HSR primarily increases the COVID-19 transmission in cities that are 700–1400 km away. Furthermore, we examine the economic loss, which indicates that all cities in our sample suffered losses of approximately USD 0.62 billion owing to HSR connections to Wuhan. The internal mechanism suggests that intercity HSR connections spread the COVID-19 intercity transmission by increasing cross-town human mobility.

This study contributes to the literature on the transmission and socioeconomic consequences of COVID-19. Several studies focus on the driving force of the COVID-19 spread, such as social networks, college student travels, intracity mobility, and subways (Glaeser et al., 2020; Harris, 2020; Mangrum and Niekamp, 2022; Kuchler et al., 2022). Li and Ma (2020), whose study is the closest to ours, found that the rapid development in transportation infrastructure and liberalization of migration restrictions in the recent decade could explain approximately 28% of the COVID-19 infections outside the Hubei province. However, because Li and Ma (2020) did not rule out intracity transmission of COVID-19 and were unable to analyze transient population intercity migration owing to the Population Census Data, they most likely underestimated the effect of transportation infrastructure on the COVID-19 intercity transmission.4 Emphasizing the transmission of COVID-19 in China, Qiu et al. (2020) investigated the human-to-human transmission rate of COVID-19 in cities throughout China and estimated the effectiveness of public health policies in reducing the number of COVID-19 infections. Fang et al. (2020) examined the effect of Wuhan’s lockdown policy on the transmission of COVID-19, and Li et al. (2022) discussed the effects of officials’ professionalism on their response to and performance in fighting the COVID-19 pandemic. However, we highlight the role of intercity HSR connections in the transmission of COVID-19 without coercive government intervention. Additionally, a branch of literature investigated the socioeconomic consequences of COVID-19, such as cross-country travel, air quality, and economic activity (Graf et al., 2020; He et al., 2020a; Brinkman and Mangum, 2021; Chen et al., 2021). This study discusses the potential economic loss owing to intercity HSR connections with Wuhan during the early stages of the COVID-19 outbreak.

Furthermore, this research is related to the literature on the effects of transportation on various socioeconomic factors. Numerous studies have been conducted to investigate the impact of transportation on urbanization, economic growth, trade, and the environment (Baum-Snow, 2007; Duranton and Turner, 2012; Donaldson, 2018; Banerjee et al., 2020; He et al., 2020b). Moreover, recent research has examined the effects of China’s HSR on economic growth (Ke et al., 2017; Qin, 2017; Zhang, 2017), urban industry service agglomeration (Shao et al., 2017; Li and Xu, 2018), market integration (Zheng and Kahn, 2013), employment (Lin, 2017), intercity academic cooperation (Dong et al., 2020), and manufacturing firm innovation (Gao and Zheng, 2020). The current study contributes to and expands on extant literature by investigating the impact of intercity HSR connections on epidemic transmission between cities.

Our research adds to the body of knowledge about the relation between epidemic transmission and intercity transportation links. For instance, Adda (2016) estimated the causal effect of expanding transportation networks on virus spread. Tang (2017) revealed that expanding railway networks increased gross mortality rates by hastening the spread of communicable diseases. Meanwhile, Adda (2016) and Tang (2017) focused on various infectious diseases, all of which can be classified into cyclical and noncyclical and discussed the long-term impact of traffic connections on epidemic transmission. However, COVID-19 is a new type of infectious disease that has caused a public health emergency owing to its sudden and highly rapid infectiousness in a short period of time. Therefore, our research focuses on the short-term impact of transportation connections on the spread of unfamiliar and emergency epidemics.

Finally, our research has significant policy implications. It serves as a useful reference for the government to predict the direction and potential scope of virus transmission (for example, keeping a more vigilant and precise eye on cities with HSR connections to COVID-19 outbreak cities) via intercity HSR connections and develop forward-thinking prevention and control policies to better suppress the epidemic transmission when faced with similar public health emergencies in the future.

The remainder of this paper is structured as follows. Section 2 provides background information, including a brief introduction to Wuhan and the development of the COVID-19 epidemic. Section 3 introduces the empirical strategy. Section 4 describes the data and presents the descriptive statistics. Section 5 provides the primary empirical results. Section 6 presents further study and mechanism analysis. Finally, Section 7 concludes the study and discusses the research limitations.

2. Background

2.1. Traffic role of Wuhan in mainland China

The railway is a particularly important mode of transport between cities in China. The State Council has revised the mid-to-long term railway development plan to sign for up to CNY 4000 billion (USD 627 billion) in HSR construction projects (Lin, 2017). According to the statistical report released by China’s Ministry of Transport, the HSR accounted for 60% of the total railway passengers during the Chinese Spring Festival travel season in 2019.5

As one of China’s eight national central cities and the capital of the Hubei province, Wuhan has an advantageous location and is one of the most important HSR hubs in China (Li et al., 2021). Wuhan is served by the Beijing–Guangzhou, Wuhan–Jiujiang, Wuhan–Shijian, Yangtze HSRs, including the Shanghai–Chengdu (Chongqing) and Wuhan–Xiaogan HSRs. The national HSR network project of the eight north–south and east–west corridors (the primary corridors of China’s HSR) includes the Beijing–Guangzhou and Yangtze HSRs. Wuhan is connected to approximately half of all prefecture-level cities in China (located in the east, south, west, and north), indicating that Wuhan is the “bridge” between China’s north–south and east–west ends via HSR connections.

Our baseline result shows that connecting to Wuhan through HSR leads to an average of 45% increase in the local COVID-19 confirmed cases, which is larger than that found by Li and Ma (approximately 28%). To some extent, our study and that of Li and Ma (2020) are different in terms of methodology, empirical data and research limitations.

5 Information source: http://www.mot.gov.cn/guowuyuanxinx/201903/t20190304_3171067.html (in Chinese).
2.2. The outbreak of COVID-19 in Wuhan

The COVID-19 outbreak began at the end of 2019 in Wuhan. The Chinese official media reported that COVID-19 had widespread human-to-human transmission on January 20, 2020—just a few days before the Chinese Spring Festival, China’s busiest travel season. Wuhan’s government imposed lockdown on the entire city on January 23, 2020, to tackle the unexpected epidemic. According to data released at a press conference in Hubei province on January 26, 2020, more than five million people left Wuhan prior to the implementation of the lockdown policy by the Wuhan government on January 23, 2020. More than 90% of the confirmed COVID-19 cases reported by provincial and municipal health commissions in areas other than Wuhan were imported early in the epidemic, and the affected people had a history of living or traveling in Wuhan. Hence, if HSR connections would increase human mobility between Wuhan and other cities, more confirmed COVID-19 cases were likely to be reported in cities connected to Wuhan by HSR compared with other cities.

3. Empirical strategy

We used the following regression model to investigate the effect of intercity HSR connections on the intercity COVID-19 transmission:

$$COVID - 19_p = \alpha_0 + \alpha_1 HSR_p + \beta X + \theta_p + \epsilon_p$$  \hspace{1cm} (1)

where $COVID - 19_p$ represents the number of confirmed cases per 10,000 population in city $i$ in province $p$. We chose the number of confirmed cases on February 6, 2020 to measure the extent of the intercity COVID-19 transmission for the following reasons. First, most confirmed COVID-19 cases reported by provincial and municipal health commissions in areas other than Wuhan were imported. Second, on January 23, 2020, Wuhan’s government enacted the lockdown policy. Third, the incubation period for COVID-19 was 14 days (Guan et al., 2020; Li et al., 2020), with February 6, 2020 being the 14th day after the lockdown date. Hence, selecting this date (February 6, 2020) as our baseline regression date allowed us to investigate all potential infections in cities other than Wuhan. And using the data on confirmed COVID-19 cases per 10,000 population reported two days before and after February 6, 2020 did not change our basic results.

$HSR_p$ is an indicator variable that equals 1 if city $i$ in province $p$ is directly connected with Wuhan by HSR; otherwise, it equals 0. HSR lines form a national traffic network, theoretically suggesting that residents of cities on an HSR line can travel to Wuhan via several transfers. However, we emphasized the impact of direct HSR connections to Wuhan rather than the network effect of HSR lines. To rule out potential HRS network effects, we conducted several placebo tests in five cities with similar political, economic, and transportation status to Wuhan to consider the network effect of HSR lines. $X$ is the control variables’ vector, including the per capita gross domestic product (GDP) (logged); number of hospital beds per 10,000 population (logged); geographical distance from city $i$ to Wuhan (logged); number of roads, airline, and waterway transportation passenger capacity (logged); number of road and waterway freight volumes (logged); total number of employees in the transportation, storage, and postal service industries per 10,000 population (logged); difference in dialects between city $i$ and Wuhan; whether city $i$ operates flights to Wuhan; and whether city $i$ has an HSR station given the minimized economic cost simulated by ArcGIS. We used the vector of control variables to control a city’s urban economic development, urban medical conditions, urban transportation conditions, freight transportation, distance from city $i$ to Wuhan, and cultural differences between city $i$ and Wuhan. $\epsilon_p$ is the classical error term. $\alpha_1$ is the coefficient of interest, indicating the marginal effect of intercity HSR connections on the number of confirmed COVID-19 cases. If $\alpha_1$ is positively significant, the intercity HSR connections strengthen the intercity transmission of COVID-19.

Furthermore, reverse causation, measurement errors, and missing variables are widely considered the primary sources of endogeneity (Atkin, 2016), which may bias our estimation of the causal effect of intercity HSR connections on the COVID-19 transmission. We will discuss the sources of endogenous problems in detail.

First, we believe that reverse causation is unlikely because the COVID-19 epidemic was an unexpected emergency health event and the intercity transmission of COVID-19 occurred after the intercity HSR connections. Moreover, the construction of HSR lines is motivated by transportation convenience and economic development, rather than by infectious disease prevention and control.

Second, there is the possibility of measurement errors. COVID-19 spread quickly in 2020, just before the Chinese Spring Festival, when workers returned home to celebrate the Chinese New Year. This caused Chinese pharmaceutical manufacturers to reduce capacity, thereby making it difficult to produce enough COVID-19 tests to support the number of patients in severely affected areas, such as Wuhan and other cities in Hubei province, potentially leading to an underestimation of the number of patients diagnosed during the early COVID-19 outbreak.

Finally, issues of missing variable could arise in our study for two reasons. First, there may be underlying political ties between Wuhan and certain cities, which could artificially strengthen HSR construction and personnel flow via administrative forces derived from political policies. Second, the connections with the upstream and downstream of Wuhan’s industrial chains are also an underlying factor that could influence the migration of a population; thus, cities on the upstream and downstream of the industrial chain of Wuhan could be expected to have greater people flow to and from Wuhan. In summary, the problem of missing variable problem primarily results from the potential political and economic links, such as national policies and industrial chains, which are probably associated with HRS connections to Wuhan.

To manage measurement errors and omitted variables, we used the following strategies. First, because few patients were diagnosed in non-Hubei provinces during the early outbreak and most confirmed cases in cities outside of Hubei province were imported, we believed that the COVID-19 tests were relatively adequate in non-Hubei provinces and the numbers of confirmed cases reported were relatively objective. To solve measurement error problems in confirmed cases, we chose cities outside of Hubei province as our baseline regression sample. In addition, we used the data on confirmed COVID-19 cases per 10,000 population reported two days before and after February 6, 2020 for robustness checks.

Second, to address the endogeneity of so-called political and industrial chain connections, we excluded specific subsamples. According to the Chinese Ministry of Railways’ medium- and long-term railway system plan, key cities and those with large populations are more likely to be directly connected with HSR. We express our gratitude toward the referee for raising the issue of freight transport. We present the estimated coefficients of freight transport in Table A1 in the Appendix.

8 We express our gratitude toward the referee for raising the issue of freight transport. We present the estimated coefficients of freight transport in Table A1 in the Appendix.

9 For instance, the Chinese central government issued the “Development Plan for City Groups in the Middle Reaches of the Yangtze River,” which included several cities in the provinces of Hubei, Hunan, and Jiangxi in 2015. Based on this plan and its development policy, the three key cities, namely Wuhan (the capital of Hubei Province), Changsha (the capital of Hunan Province), and Nanchang (the capital of Jiangxi Province), are required to comprehensively strengthen communications and cooperation in education, technology, medicine, and health and promote cultural prosperity and human resource development.
served by HSR lines, influencing the directions of HSR lines. Hence, nonkey cities and those with small populations have relatively little impact on the directions of HSR lines. In other words, small cities are less likely to receive political benefits as non-key and small cities relatively lack the bargaining power to demand HSR connections from the central government compared with key cities owing to their economic status and larger scale. Thus, whether linked with Wuhan by HSR in non-key and small cities is relatively more exogenous than in the key and large cities. Therefore, we conducted robustness assessments by gradually excluding provincial capitals, subprovincial cities, and those with large populations. We obtained similar conclusions and further confirmed the validity of our baseline results.

Finally, according to Faber (2014), we created a dummy variable that equaled 1 if the city connected with Wuhan via HSR given the lowest construction costs; otherwise, it equaled 0. We considered this new dummy variable the IV for variable HSR and adopted the IV approach to rule out the endogeneity as a robustness check. We obtained similar conclusions.

4. Data and descriptive statistics

4.1. Data

Since the beginning of the COVID-19 outbreak, an official WeChat account called DXYS (a social media platform similar to Facebook) has been updating its data on confirmed cases, both cured and fatal, in 31 provinces and autonomous regions, including Hong Kong, Macao, and Taiwan.10 From DXYS, we collect data on the number of confirmed cases from February 4 to February 8, 2020. We also collect the number of days for reviving in an estimated 297 Chinese cities. The data on fatalities in cities with confirmed cases in mainland China range from February 22 to February 26, 2020. Furthermore, we compute the number of days between January 23, 2020 (the date Wuhan implemented the lockdown policy) and the date when the newly added confirmed cases of a city are consistently zero for 14 days.

The data on whether the cities are linked to Wuhan via HSR are collected from the 12306 China railroad website (China railroad administration official ticketing website). If a traveler can purchase one HSR ticket to travel from Wuhan to another city in December 2019 directly, this city will be linked to Wuhan by HSR. Otherwise, this city is not connected to Wuhan by HSR.

To examine a city’s economic and social development, we collect the urban economic and social indicators, including the per capita GDP; total urban residential population number of hospital beds; road, airline, and waterway transportation passenger capacity; road and waterway freight transport volumes; and total number of employees in the transportation, storage, and postal service industries from the China City Statistical Yearbook of 2020.11 To control relations between Wuhan and other cities, such as cultural and traffic connections, we collect data on different dialects between cities from Liu et al. (2015), whether the city has flights to Wuhan from the Civil Aviation Administration of China, and whether the city has an HSR station. Finally, we calculate whether the city is connected to Wuhan via HSR under minimized economic costs, namely, the variable HSR COST, and use it as the IV for the key independent variable.

10 The epidemic data source for the DXYS WeChat official account is the People’s Daily, a public institution directly under the Communist Party of China (CPC) and a news agency of the Central Committee of China. We compare the data from the DXYS WeChat official account with the data from the National Health Commission of China, and we find that they are exactly the same.
11 We complement missing variables in the 2020 China City Statistical Yearbook with economic and social development reports from each city’s statistical bureau for 2019.

4.2. Descriptive statistics

As reported in Table 1, the full sample size is 245. We divide the samples into non-Hubei and Hubei subsamples (except Wuhan). Panel A reports on the epidemic and population variables. Panel A presents that in the non-Hubei subsample, on average the number of infections per 10,000 population is 0.064, the city population is approximately 4.87 million, and the absolute value of infections is 35.64. However, in the Hubei subsample, the mean of the number of infections per 10,000 population is 2.35, the mean of the city population is approximately 3.63 million, and the mean of the number of infections is 76.42. The difference in COVID-19 infections between the two subsamples is significant. In addition, the difference in fatalities per 10,000 populations between non-Hubei and Hubei province cities is substantial (0.001 vs. 0.121). The mean number of days for reopening in cities outside the Hubei province is approximately 35, implying that these cities averagely took 35 days to report no newly confirmed cases for 14 consecutive days after Wuhan’s lockdown policy.

Panel B presents the HSR variables, including whether cities connect with Wuhan via HSR, whether cities have an HSR station given the minimized economic cost, and whether cities connect with Wuhan via HSR given the minimized economic cost. The summary statistics for whether cities connect with Wuhan via HSR, the key explanatory variable in our study, indicate that 44.3% of non-Hubei province cities connect with Wuhan via HSR, which is lower than that of Hubei province cities (60%).

Panel C includes additional variables, including the GDP per capita (logged); number of beds per 10,000 population (logged); distance to Wuhan (logged); number of road, airline, and waterway transportation passenger capacity (logged); road freight volume (logged); waterway freight volume (logged); total number of employees in the transportation, storage, and postal service industries per 10,000 population (logged); dialect difference between cities; and whether the cities have a flight to Wuhan. Taking “whether cities have a flight to Wuhan” as an example, we can see that approximately 23% of non-Hubei province cities operate at least one flight to Wuhan, whereas only one Hubei province city had an airline connection to Wuhan by the end of 2019.

To visualize significant differences in confirmed COVID-19 cases between the two subsamples, we segregated the non-Hubei subsample into two groups: a group unconnected with Wuhan by HSR and a group connected with Wuhan by HSR. Fig. 1A and B illustrate histograms of the number of infections per 10,000 population and number of infections between the two groups, respectively. The mean number of infections per 10,000 population and number of infections in the group connected with Wuhan by HSR are significantly higher than those in the group not connected with Wuhan by HSR, indicating a highly positive relation between intercity HSR connections and intercity COVID-19 transmission.

5. Empirical results

5.1. Basic results

The basic empirical results of the effect of intercity HSR connections on COVID-19 intercity transmission are reported in Table 2. First, we use the entire sample as the dependent variable with confirmed city-level COVID-19 cases per 10,000 people on February 6, 2020. The results with no control variables but provincial fixed effects are shown in Column 1. The coefficient of interest is 0.051, which is statistically insignificant. Thereafter, we add the control variables and provincial fixed effects to the regression equation, and the coefficient in Column 2 also lacks statistical significance. Owing to the significant difference in the number of confirmed cases between cities in Hubei province and those outside the province, we only keep the cities outside Hubei province. Column 3 displays the empirical results. The coefficient of interest is 0.029, which is statistically significant at the 5% level, implying that if city $i$ is connected to Wuhan via HSR, the number of confirmed cases per
10,000 increases by 0.029, accounting for 45% of the total infections. Given that the average population scale in cities outside the Hubei province is 4.87 million, we estimate that HSR connections to Wuhan increase the number of confirmed cases by 14 at the city level. We substitute the dependent variable with the number of confirmed COVID-19 cases per 10,000 people in a city two days before and after February 6, 2020. The results are reported in the last four columns, and the coefficients are significantly positive and close to those shown in Column 3.

5.2. Robustness assessments and placebo tests

First, we first change the measurement of the dependent variable by

Table 1

Descriptive statistics.

| Variables | Non-Hubei | Hubei (except Wuhan) |
|-----------|-----------|----------------------|
|           | Obs. | Mean  | S.D. | Obs. | Mean  | S.D. |
| Panel A: Epidemic and Population Variables | | | | | | |
| Confirmed cases per 10,000 population | 235 0.064 0.078 | 10 2.348 1.158 |
| Population (10,000) | 235 486.944 374.364 | 10 363.173 173.923 |
| Number of confirmed cases | 235 35.638 59.598 | 10 764.200 439.259 |
| Fatalities per 10,000 population | 235 0.001 0.002 | 10 0.121 0.105 |
| Number of days for reviving | 235 35.464 9.054 | 10 50.500 3.951 |
| Panel B: HSR Variables | | | | | | |
| Whether cities connect with Wuhan by HSR | 235 0.443 0.498 | 10 0.600 0.516 |
| Whether cities have an HSR station given the minimized economic costs | 235 0.745 0.437 | 10 0.700 0.483 |
| Whether cities connect with Wuhan by HSR given the minimized economic costs | 235 0.413 0.493 | 10 0.600 0.516 |
| Panel C: Other Variables | | | | | | |
| GDP per capita (log) | 235 10.870 0.744 | 10 11.098 0.350 |
| Number of beds per 10,000 population (log) | 235 4.093 0.265 | 10 4.171 0.154 |
| Distance to Wuhan (log) | 235 6.655 0.557 | 10 4.908 0.855 |
| Road transportation passenger capacity (log) | 235 7.657 1.961 | 10 8.186 0.717 |
| Airline transportation passenger capacity (log) | 235 2.983 2.900 | 10 1.607 2.594 |
| Waterway transportation passenger capacity (log) | 235 2.175 2.288 | 10 2.384 1.920 |
| Road freight volume (log) | 235 4.276 3.786 | 10 6.390 1.940 |
| Waterway freight volume (log) | 235 2.196 0.627 | 10 1.670 0.748 |
| Number of people employed in transportation, storage, and postal services per 10,000 population (log) | 235 0.230 0.422 | 10 0.100 0.316 |
| Dialect difference between cities | 235 2.196 0.627 | 10 1.670 0.748 |

Notes: Data Sources: People's Daily and DXYS (WeChat official account), Statistical Bulletin on National Economic and Social Development (2019), China City Statistical Yearbook (2020) of 245 cities in China, and Liu et al. (2015). “Number of days for reviving” refers to the number of days between January 23, 2020 and the date that the newly added confirmed cases of a city are consistently zero for 14 days.

Fig. 1. The Difference in Confirmed Cases between the Cities

Notes: Data Source is DXYS (WeChat official account) and the 12306 China railway website.

Table 2

HSR and the number of confirmed cases.

| Dependent variable: Number of confirmed cases per 10,000 population | Feb. 6 | Feb. 4 | Feb. 5 | Feb. 7 | Feb. 8 |
|---------------------------------------------------------------|-------|-------|-------|-------|-------|
|                                                              | (1)   | (2)   | (3)   | (4)   | (5)   |
| HSR                                                           | 0.051 | 0.025 | 0.029**| 0.024**| 0.027**| 0.032**| 0.035**|
|                                                              | (0.043)| (0.026)| (0.012)| (0.009)| (0.010)| (0.013)| (0.014)|
| Observations                                                 | 245   | 245   | 235   | 235   | 235   | 235   | 235   |
| Control Variables                                            | No    | Yes   | Yes   | Yes   | Yes   | Yes   | Yes   |
| Province Fixed Effects                                       | Yes   | Yes   | Yes   | Yes   | Yes   | Yes   | Yes   |
| Adjusted R-squared                                          | 0.767 | 0.819 | 0.307 | 0.329 | 0.318 | 0.305 | 0.303 |

Notes: Standard errors are heteroscedasticity robust errors. *, **, and *** represent significance levels of 10%, 5%, and 1%, respectively.
employing the number of confirmed cases as the dependent variable. Table 3 shows that the number of confirmed COVID-19 cases in cities linked to Wuhan via HSR is approximately 12 higher than in other cities. The conclusions are quite similar to those in Table 2. Furthermore, we replace the dependent variable with the number of confirmed COVID-19 cases at the city level two days before and after February 6, 2020 and obtain similar results.

Different HSR lines form a national HSR network; thus, the significant coefficients in Table 2 may represent the effect of intercity HSR connections on the intercity transmission of COVID-19 and capture the potentially slight effect of the national HSR network on the intercity transmission of COVID-19. Fortunately, the characteristics of the early outbreak (before the lockdown policy in Wuhan) of COVID-19 in China provide an opportunity to solve this challenge. Wuhan is the center of the early outbreak in China, spreading to the entire country. Theoretically, suppose the entire national HSR network contributes to the effect of intercity HSR connections on the intercity transmission of COVID-19. In that case, we probably find that HSR connections increase the number of confirmed cases in a city even though the city is connected to other cities (barring Wuhan) via HSR.

We design placebo tests in Guangzhou, Hangzhou, Jinan, Xi’an, and Chengdu to investigate the effect of the national HSR network on the COVID-19 intercity transmission because these five cities are important nodes in the HSR network. Guangzhou, for example, is the most important transportation junction in southern China with connections to the Beijing-Guangzhou, Guangzhou-Shenzhen-Hong Kong, and Guiyang-Guangzhou HSRs among other lines. According to the epidemic data, on February 6, 2020, the number of confirmed cases in Guangzhou was 284, indicating a relatively severe outbreak outside the Hubei province, approximately eight times the mean value of the number of confirmed cases (35.64) in non-Hubei cities. Hence, if the coefficient of the estimated variable (HSR) for Guangzhou is significantly positive, we also capture the effect of the national HSR network on the COVID-19 intercity transmission, as shown in Table 2; otherwise, we do not. Therefore, we regress the number of confirmed cases on HSR (whether cities connect with Guangzhou via HSR).

Table 4 presents the empirical results of the placebo tests. The findings reveal no statistically significant effect of connecting with those five cities via HSR on the intercity transmission of COVID-19. Hence, given the intercity HSR connections and other control variables, the effect of the national HSR network on the intercity transmission of COVID-19 is minor. We replace the dependent variable with the number of confirmed cases. The empirical results, which are similar to those in Table 4, are shown in Table A2.

As mentioned in Section 3, there is a possibility of endogeneity induced by omitted variables. The following is the approach adopted to resolve this potential endogeneity. First, we gradually exclude the key cities and those with large populations. The empirical results are presented in Table A5. The coefficients of interest are significantly positive and similar in magnitude. According to Table A5, we do not seem to face serious endogeneity induced by potentially omitted variables.

Second, we adopt the IV approach to further resolve potential endogeneity. The IV is constructed as follows. First, based on geographic features (e.g., slope, altitude, etc.), we calculate the ideal HSR lines that minimize the economic cost of construction using the ArcGIS software. Second, according to the economic costs of minimizing HSR lines, we calculate whether city i of province p is connected with Wuhan via HSR. The IV is called HSR_COST. The first- and second-stage equations of the IV approach are as follows:

\[
H SR_{ip} = \beta_0 + \beta_1 H SR_{COST, ip} + \lambda X + \theta_p + \mu_p \tag{2}
\]

\[
COVID_{19} \sim \gamma_0 + \gamma_1 H SR_{ip} + \phi X + \theta_p + \omega_p \tag{3}
\]

Table 3: Robustness assessment—number of confirmed cases.

| Dependent variable: Number of confirmed cases | Feb. 6 | Feb. 4 | Feb. 5 | Feb. 7 | Feb. 8 |
|---------------------------------------------|-------|-------|-------|-------|-------|
| HSR                                         | 18.462* (10.410) | 10.053** (4.179) | 11.238** (4.609) | 13.349** (5.358) | 14.284** (5.615) |
| Observations                                 | 245   | 235   | 235   | 235   | 235   |
| Control Variables                            | Yes   | Yes   | Yes   | Yes   | Yes   |
| Adjusted R-squared                           | 0.685 | 0.657 | 0.657 | 0.657 | 0.658 |

Table 4: Placebo Test—Supposing the Outbreak is in Other Cities.

| Dependent variable: Number of confirmed cases per 10,000 population | Guangzhou | Hangzhou | Jinan | Xi’an | Chengdu |
|---------------------------------------------------------------------|-----------|----------|------|------|---------|
| HSR                                                                 | 0.018     | 0.016    | 0.007| 0.002| 0.017   |
| Observations                                                        | 0.015 (0.013) | 0.008 (0.010) | 0.010(0.016) |
| Control Variables                                                    | Yes       | Yes      | Yes  | Yes  | Yes     |
| Effect                                                              | Adjusted R-squared | 0.277 | 0.298 | 0.272 | 0.264 | 0.275 |

Notes: Standard errors are heteroscedasticity robust errors, *, **, and *** represent significance levels of 10%, 5%, and 1%, respectively. When the absolute value of COVID-19 infections is the dependent variable, the natural logarithm of GDP, resident population, and hospital beds are substituted for the corresponding control variables.

In Equation (2), HSR_COST, is a dummy variable that equals 1 if the city connects with Wuhan via HSR given the minimized construction costs; otherwise, it equals 0.12 The variable HSR_COST, is the IV for variable HSR, and the remainder of the variables are the same as in Equation (1). \( \mu_p \) and \( \omega_p \) are the classical error terms as well.

The estimated IV results are presented in Table 6, and the first-stage results are presented in Table A3 in the Appendix. The estimated coefficients indicate that being linked to Wuhan via HSR increases the number of confirmed cases in the connected cities by 0.023 per 10,000 population, which is statistically significant at the 5% level. The C-D Wald F-test value suggests that the seriously estimated bias induced by weak IV almost does not occur. Subsequently, we conduct a robustness assessment of the IV estimation by substituting the number of infections.

12 The suffix “COST” means that we calculate the variable based on the minimum construction economic cost of HSR, but is not the real construction economic cost of HSR.
per 10,000 population with the number of infections. The results are presented in Table A4, which shows empirical results similar to those shown in Table 3.

To summarize, the effect of intercity HSR connections on the COVID-19 intercity transmission is significantly positive. The number of confirmed cases per 10,000 population in cities connected to Wuhan via HSR is 0.029 higher on average than in other cities. According to the average population and city-level confirmed COVID-19 cases, the intercity HSR increases the probability of the COVID-19 infection by 45% and the number of COVID-19 patients by approximately 14.

5.3. Heterogeneous effects

As Dong et al. (2020) reported, the effect of HSR connections on intercity cooperation among highly skilled workers is heterogeneous in terms of urban geographical distance and HSR connections. We divide each city into three categories based on their geographical distance to Wuhan, 0–700 km, 700–1400 km, and more than 1400 km, and generate three dummy variables. Subsequently, we use the interaction terms of the dummy variables and variable HSR to examine the heterogeneity of the effect of intercity HSR connections on the intercity transmission of COVID-19 based on the geographical distance between the cities. The estimated coefficients of the three interaction terms and their 95% confidence intervals are shown in Fig. 2.

As illustrated in Fig. 2, the impact of intercity HSR connections on the number of COVID-19 infections per 10,000 population is positive for all distance ranges to Wuhan; however, only the coefficient of HSR for cities located within the 700–1400 km range is statistically significant at the 5% statistical level, indicating that the effect of intercity HSR connections is primarily driven by cities located 700–1400 km away from Wuhan. Given that HSR trains travel at approximately 300 km per hour, the effect is most noticeable in cities 2.5–5 h from Wuhan. The impact of intercity HSR connections on the COVID-19 intercity transmission varies depending on the geographical distance to Wuhan. This effect's heterogeneity is most likely due to the trade-off between other intercity transportation modes (e.g., coaches or private cars for relatively short distance travel and airlines for longer distance travel) and HSR.

6. Further analysis and mechanism

6.1. Further analysis of the COVID-19 fatalities

The median time from diagnosis to death in the COVID-19 cases, according to Zhou et al. (2020), is 18 days. We use the number of

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### Table 5

Exclusion of omitted variable effects.

| Dependent variable: Number of confirmed cases per 10,000 population | Excluding provincial capitals | Excluding provincial capitals and subprovincial cities | Excluding provincial capitals, subprovincial cities, and the population of the city is greater than six million | Excluding provincial capitals, subprovincial cities, and the population of the city is greater than five million | Excluding provincial capitals, subprovincial cities, and the population of the city is greater than four million |
|---|---|---|---|---|---|
| HSR | 0.032*** | 0.031** | 0.027* | 0.036* | 0.044** |
| (0.012) | (0.013) | (0.015) | (0.019) | (0.019) |
| Observations | 296 | 201 | 162 | 142 | 112 |
| Control Variables | Yes | Yes | Yes | Yes | Yes |
| Province Fixed Effects | Yes | Yes | Yes | Yes | Yes |
| Adjusted R-squared | 0.299 | 0.297 | 0.267 | 0.290 | 0.263 |

Notes: Standard errors are heteroscedasticity robust errors. *, **, and *** represent significance levels of 10%, 5%, and 1%, respectively.

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### Table 6

2SLS results.

| Dependent variable: Number of confirmed cases per 10,000 populations | Feb. 6 | Feb. 4 | Feb. 5 | Feb. 7 | Feb. 8 |
|---|---|---|---|---|---|
| HSR | 0.044 | 0.027 | 0.023** | 0.018** | 0.021** | 0.025* | 0.027** |
| (0.043) | (0.023) | (0.010) | (0.008) | (0.009) | (0.010) | (0.011) |
| Observations | 245 | 245 | 235 | 235 | 235 | 235 | 235 |
| Control Variables | No | Yes | Yes | Yes | Yes | Yes | Yes |
| Province Fixed Effects | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| Adjusted R-squared | 0.767 | 0.819 | 0.306 | 0.328 | 0.317 | 0.304 | 0.301 |
| C-D Wald F test | 1395.333 | 1116.351 | 1041.588 | 1041.588 | 1041.588 | 1041.588 | 1041.588 |

Notes: Standard errors are heteroscedasticity robust errors. The instrumental variable is whether a city is connected with Wuhan via HSR under the minimum construction economic cost of HSR, *, **, and *** represent significance levels of 10%, 5%, and 1%, respectively.
COVID-19 fatalities per 10,000 people in city $i$ in province $p$ on February 24, 2020 as dependent variables, adding 18 days to the baseline regression date. The other variables are identical to those in Equation (1). Table 7 summarizes the findings. Intercity HSR connections raise the number of fatalities in connected cities by 0.001 per 10,000 population. Furthermore, we set a two-day interval before and after February 24, and all the coefficients are positive and significant. Therefore, we can deduce that connections to Wuhan via HSR significantly increase fatalities in the connected cities by augmenting the base of the confirmed COVID-19 cases.

6.2. Further analysis of economic loss

This section evaluates the average economic loss induced by connections to Wuhan via HSR during the early period of COVID-19 for cities outside the Hubei province based on direct medical expenditures and indirect economic cost.

The baseline results show that connections to Wuhan via HSR increase the number of confirmed cases by an average of 14 at the city level. The National Healthcare Security Administration in China states that the per capita medical expenses for hospitalized patients diagnosed with COVID-19 reach CNY 21,500, on average, as on April 6, 2020. Therefore, the economic loss for total direct medical expenditure achieves CNY 301,000, corresponding to USD 44,270 for each city with HSR connections to Wuhan.

Furthermore, on January 23, 2020, the local government of Wuhan implemented a lockdown policy, and other cities in China followed suit, suspending all indoor economic activities, such as closed management of residential communities; for example, the suspension of dine-in food in the catering industry and the closure of movie theaters (Chen et al., 2021). Moreover, the Chinese government stipulated that dine-in food and other indoor economic activities could be gradually revived only when there were no new local cases for 14 days (the so-called “14-days principle” in China), a full incubation period of COVID-19. Because HSR connections to Wuhan significantly increased the number of COVID-19 confirmed cases, we believe that HSR connections to Wuhan postponed the number of days for reviving activities and consumption losses, suggesting that if we consider other factors, such as firms’ production and even psychological loss among the public, the total loss caused may be even much greater.

6.3. Mechanism

This subsection discusses the mechanism of the impact of HSR connections to Wuhan on the intercity transmission of COVID-19. Intercity transmission of COVID-19 is strongly dependent on human mobility across cities. We consider that HSR connections to Wuhan increase the number of travelers from Wuhan to the connected cities. We obtain the intercity population migration data from Baidu Migration from January 1 to 22, 2020, a travel map provided by Baidu, the largest Chinese search engine. The population migration data daily record the proportion of the population traveling from Wuhan to each city, which we use as the marginal effect of intercity HSR connections on the number of days for reviving the activities in each city. If $\delta_1$ is positively significant, intercity HSR connections postpone the number of days for reviving activities and increase the economic costs for cities with HSR connections to Wuhan.

Table 8 displays the empirical results. According to the estimated coefficients shown in Table 8, HSR connections to Wuhan, on average, delay the date when a city’s newly added confirmed cases are consistently zero for 14 days by 1.87 days. According to Chen et al. (2021), daily offline consumption in China fell by an average of CNY 21.6 million per city per day during the first 12-week period following the Wuhan lockdown policy. Therefore, we argue that the indirect economic cost is approximately CNY 40.39 million (21.6 \times 1.87 = 40.39)—approximately USD 5.9 million—loss for the cities connected to Wuhan via HSR. Therefore, combining the direct medical expenditure and consumption loss, we reckon that the total loss for each city achieves CNY 40.69 million (approximately USD 6 million). Since there are 104 cities outside the Hubei province connected to Wuhan via HSR in our sample, the total economic loss for all cities with HSR connections to Wuhan reaches approximately CNY 4.23 billion (40.69 \times 104 = 4231.76), approximately USD 0.62 billion.

There is a caveat that the above estimated value induced by HSR connections to Wuhan during the early period of COVID-19 was probably underestimated. We only capture the direct medical expenditure and consumption losses, suggesting that if we consider other factors, such as firms’ production and even psychological loss among the public, the total loss caused may be even much greater.

### Table 7

| Dependent variable: Number of COVID-19 fatalities per 10,000 population | Feb. 24 | Feb. 22 | Feb. 23 | Feb. 25 | Feb. 26 |
|---|---|---|---|---|---|
| HSR | 0.004 | 0.002 | 0.001** | 0.001** | 0.001** |
| (0.003) | (0.002) | (0.000) | (0.000) | (0.000) | (0.000) |
| Observations | 245 | 245 | 235 | 235 | 235 |
| Control Variables | No | Yes | Yes | Yes | Yes |
| Province Fixed Effects | Yes | Yes | Yes | Yes | Yes |
| Adjusted R-squared | 0.528 | 0.644 | 0.067 | 0.064 | 0.064 |

Notes: Standard errors are heteroscedasticity robust errors. *, **, and *** represent significance levels of 10%, 5%, and 1%, respectively.

### Table 8

| Dependent variable: Number of days for activity revival | (1) | (2) | (3) |
|---|---|---|---|
| HSR | 4.843*** | 4.265*** | 1.870* |
| (1.091) | (1.263) | (1.289) |
| Observations | 235 | 235 | 235 |
| Control Variables | No | Yes | Yes |
| Province Fixed Effects | No | Yes | Yes |
| Adjusted R-squared | 0.067 | 0.238 | 0.315 |

Notes: Standard errors are heteroscedasticity robust errors. *, **, and *** represent significance levels of 15%, 10%, 5%, and 1%, respectively.

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13 Information source: [http://www.gov.cn/xinwen/2020-04/12/content_5501508.htm](http://www.gov.cn/xinwen/2020-04/12/content_5501508.htm) (in Chinese).
Table 9
Effect of high-speed railway on human mobility across cities.

| Dependent variable: Proportion of the population traveling from Wuhan to each city | Jan. 1–23 | Jan. 1–9 | Jan. 10–23 |
|---|---|---|---|
| HSR | 8.989*** | 2.024*** | 2.849*** | 1.452*** |
| Observations | 5170 | 5170 | 2115 | 3055 |
| Control Variables | No | Yes | Yes | Yes |
| Date Fixed Effects | Yes | Yes | Yes | Yes |
| Province Fixed Effects | Yes | Yes | Yes | Yes |
| Adjusted R-squared | 0.457 | 0.711 | 0.760 | 0.711 |

Notes: Standard errors are heteroscedasticity robust errors. *, **, and *** represent significance levels of 10%, 5%, and 1%, respectively. We obtain the across-city population migration data from Baidu Migration during the period January 1–23, 2020, a travel map offered by the largest Chinese search engine, Baidu.

We investigate the internal mechanism and find that intercity HSR connections intensify the diffusion of COVID-19 across cities by promoting the scale of intercity human mobility. The placebo tests suggest that the effect of the national HSR network on the intercity transmission of COVID-19 is extremely limited.

Additionally, our findings are forward looking and meaningful; thereby providing helpful reference for the government to predict the direction and possible scope of virus transmission by focusing more on cities with HSR connections to the COVID-19 outbreak cities or regions and implementing more precise anti-epidemic measures to curb the spread of COVID-19 or other epidemics at the lowest possible economic cost in the future.

Finally, we present a meaningful perspective for future research. We are primarily concerned with the short-term impact of intercity HSR connections on the COVID-19 intercity transmission and the economic loss during the early stages of the COVID-19 outbreak. The COVID-19 pandemic is still ongoing. Future research should consider the long-term effects of intercity transportation connections and the potential economic cost of transportation.

Authorship Contribution Statement

Liyang Wan: Conceptualization; Project administration; data; Software; writing—original draft, review, and editing. Qian Wan: Conceptualization; Methodology; Funding acquisition; Project administration; data; Software; writing—original draft, review, and editing; and supervision.

Declaration of competing interest

The authors declare that they have no relevant or material financial interests related to the research described in this paper.

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14 The data only recorded the precise proportion of the population traveling from Wuhan to the cities in which the proportion ranked from 1 to 100. As the proportion was very close to 0 if the proportion of the population traveling from Wuhan to a city ranked above 100, we set the proportion as 0 when the proportion of the city ranked above 100.
Appendix

Table A1
HSR and the Number of Confirmed Cases

| Dependent variable: Number of confirmed cases per 10,000 populations | Feb. 6 | Feb. 4 | Feb. 5 | Feb. 7 | Feb. 8 |
|---------------------------------------------------------------|-------|-------|-------|-------|-------|
|                                                             | (1)   | (2)   | (3)   | (4)   | (5)   | (6)   | (7)   |
| HSR                                                          | 0.051 | 0.025 | 0.029** | 0.024** | 0.027** | 0.032** | 0.035** |
|                                                             | (0.043) | (0.026) | (0.012) | (0.009) | (0.010) | (0.013) | (0.014) |
| Road freight volume                                          | −0.008 | −0.019 | −0.014 | −0.017 | −0.021 | −0.021 | −0.021 |
|                                                             | (0.025) | (0.012) | (0.010) | (0.011) | (0.013) | (0.014) | (0.014) |
| Waterway freight volume                                      | −0.007 | 0.002 | 0.002 | 0.002 | 0.002 | 0.002 | 0.002 |
|                                                             | (0.007) | (0.002) | (0.002) | (0.002) | (0.002) | (0.002) | (0.002) |
| People employed in TSP (logged)                              | 0.027 | 0.016* | 0.013* | 0.014* | 0.018* | 0.018* | 0.018* |
|                                                             | (0.037) | (0.009) | (0.008) | (0.008) | (0.009) | (0.010) | (0.010) |
| Observations                                                 | 245   | 245   | 235   | 235   | 235   | 235   | 235   |
| Control Variables                                            | No    | Yes   | Yes   | Yes   | Yes   | Yes   | Yes   |
| Province Fixed Effects                                       | Yes   | Yes   | Yes   | Yes   | Yes   | Yes   | Yes   |
| Adjusted R-squared                                          | 0.767 | 0.819 | 0.307 | 0.329 | 0.318 | 0.305 | 0.303 |

Notes: Standard errors are heteroscedasticity robust errors. * People employed in TSP means the number of people employed in transportation, storage, and postal service industries per 10,000 population. **, and *** represent significance levels of 10%, 5%, and 1%, respectively.

We find that the estimated coefficient of the variable People employed in TSP is statistically significant, which indicates that if the number of people employed in transportation, storage, and postal services per 10,000 population increases by 10%, the number of confirmed cases per 10,000 population will increase by 0.0013.15 Compared with the effect of intercity HSR connections on the intercity transmission of COVID-19, it is relatively moderate, indicating that human mobility is the driving force of the intercity transmission of epidemics compared with freight transport.

Table A2
Placebo Test—Supposing the Outbreak is in Other Cities

| Dependent variable: Number of confirmed cases | Guangzhou (1) | Hangzhou (2) | Jinan (3) | Xi’an (4) | Chengdu (5) |
|------------------------------------------------|---------------|--------------|-----------|----------|------------|
| HSR                                            | −0.352        | 10.827*      | 8.196     | 7.635    | 5.232      |
| Observations                                   | (6.502)       | (6.208)      | (5.174)   | (5.255)  | (7.982)    |
| Control Variables                              | Yes           | Yes          | Yes       | Yes      | Yes        |
| Province Fixed Effects                         | Yes           | Yes          | Yes       | Yes      | Yes        |
| Adjusted R-squared                            | 0.644         | 0.667        | 0.651     | 0.648    | 0.653      |

Notes: Standard errors are heteroscedasticity robust errors. *, **, and *** represent significance levels of 10%, 5%, and 1%, respectively. The cities in the Hubei province are excluded in the sample, and the measurement of variable HSR has changed: for example, it equals 1 if and only if the city i is connected with Guangzhou by HSR in Column 1.

15 We probably overestimate the effect of intercity freight transport on intercity COVID-19 spread. Because the variable people employed in TSP not only includes the people probably engaging in intercity freight transport but also includes the employment engaging in intracity freight transport. We cannot find a reliable strategy to solve this problem. Further, we exclude the variable People employed in TSP and still obtain similar baseline results (unreported and available upon request), implying that freight transport is probably not heavily correlated with intercity HSR connections because HSR lines are only used to carry passengers.
Table A3
First-stage Regression

| Dependent variable: HSR | (1) | (2) | (3) |
|------------------------|-----|-----|-----|
| HSR COST               | 0.928*** | 0.972*** | 0.971*** |
| (0.028)                | (0.018) | (0.019) |
| Observations           | 245  | 245  | 235  |
| Control Variables      | No   | Yes  | Yes  |
| Province Fixed Effects | Yes  | Yes  | Yes  |
| Adjusted R-squared     | 0.889| 0.898| 0.894|

Notes: Standard errors are heteroscedasticity robust errors. *, **, and *** represent significance levels of 10%, 5%, and 1%, respectively. In Column (3), we exclude the cities in the Hubei province except for Wuhan.

Table A4
IV Results—Number of Confirmed Cases

| Dependent variable: Number of confirmed cases | Feb. 6 | Feb. 4 | Feb. 5 | Feb. 7 | Feb. 8 |
|---------------------------------------------|-------|-------|-------|-------|-------|
|                                             | (1)   | (2)   | (3)   | (4)   | (5)   |
| HSR COST                                   | 38.871*** | 20.806*** | 14.171*** | 11.274*** | 12.864*** |
| (15.361)                                   | (10.329) | (4.959) | (4.097) | (4.537) | (5.252) |
| Observations                               | 245   | 245   | 235   | 235   | 235   |
| Control Variables                          | No    | Yes   | Yes   | Yes   | Yes   |
| Province Fixed Effects                     | Yes   | Yes   | Yes   | Yes   | Yes   |
| Adjusted R-squared                        | 0.684 | 0.733 | 0.657 | 0.671 | 0.660 |
| C-D Wald F test                            | 1395.333 | 1131.172 | 1054.735 | 1054.735 | 1054.735 |

Notes: Standard errors are heteroscedasticity robust errors. The instrumental variable is whether a city is connected to Wuhan via HSR under the minimum construction economic cost of HSR. *, **, and *** represent significance levels of 10%, 5%, and 1%, respectively.

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