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How Does High-Speed Rail Impact the Industry Structure? Evidence from China

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Abstract The economic implications of high-speed rail (HSR) cannot be overlooked in China. This paper studies the impact of HSR on the advancement and rationalization of industrial structure and the tertiary industry aggregation through theoretical derivation and multi-period difference-in-differences (DID) by improving the theoretical framework and empirical methods according to the characteristics of China's HSR and economic development. From analyses on urban heterogeneity and inter-industry spillover effects, the transmission mechanism and expressions of the industrial structure are also discussed. The findings show that HSR promotes tertiary industry aggregation and contributes to the transformation of the industrial structure from the primary to secondary and tertiary industry sectors, as well as realizing industrial structure advancement but irrationalization. Furthermore, HSR has a more significant influence on tertiary industry aggregation in large cities and high-density cities. Additionally, the aggregation of the transportation, warehousing, and postal sectors has been reduced, with a significant spillover effect on neighboring cities, proving the siphon effect and conduction mechanism, resulting in a structural shift in the tertiary industry, from basic to advanced sectors. The movement of human resources is a key mediator in the economic impact of HSR.

Keywords High-speed rail · Industrial aggregation · Industrial structure advancement · Industrial structure rationalization · Siphon effect · Spillover effect

JEL Classification L16 · R40 · R41 · R48

1 Introduction

With a total length of 37,900 kilometers in 2020, high-speed railways (HSR) can be found in more than 80% of China's cities. Since the opening of high-speed rail in China in 2008, the economy of the regions along the line has developed rapidly. Represented by Beijing-Guangzhou and Beijing-shanghai, as shown in Fig. 1 and Fig. 2, provinces along the Beijing-Shanghai and Beijing-Guangzhou HSR routes overlapped with provinces with high GDP in 2021, with the tertiary industry accounting for more than half of GDP. Spiekerman (1994) found that the space-time distance is compressed after the opening of HSR [1]. However, the HSR's impact on the economy is not always positive. This might result in a siphon effect, suffocating the development of small and medium-sized cities [2]. The Beijing–Shanghai HSR, for example, establishes a 1-hour shuttle between Beijing, Tianjin, and Hebei, while simultaneously enabling Beijing to absorb Tianjin and Hebei's vast resources. Without a doubt, HSR's economic effect is significant, but how does HSR transform the industrial structure? What sectors will be affected as a result of this? Is HSR going to have a siphon effect? Theoretical and empirical studies are needed to better investigate these concerns.

With the advancement of modern transportation networks, more papers on the effect of transportation infrastructure on economic growth [3–5]. Since China's HSR

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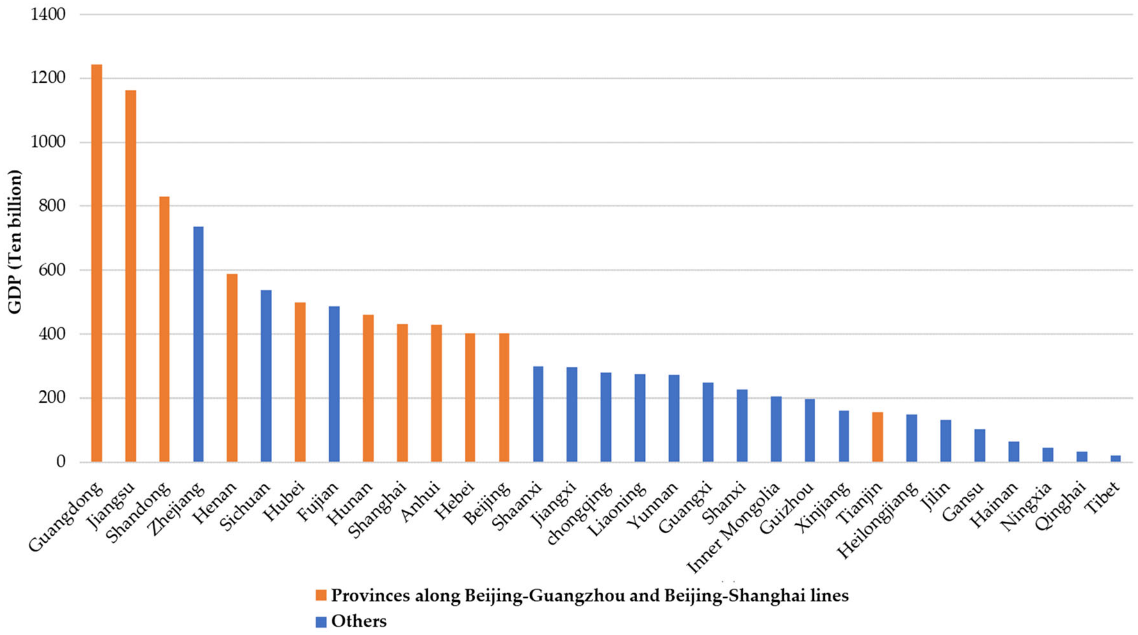

Fig. 1 GDP of provinces in China in 2021

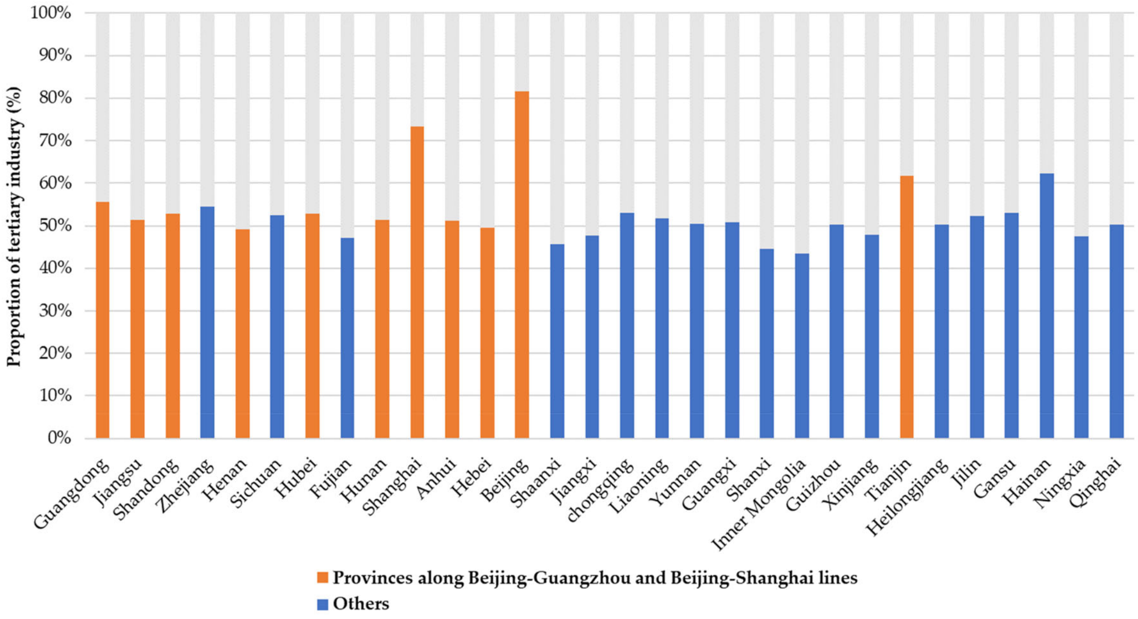

Fig. 2 Proportion of tertiary industry of provinces in China in 2021

launched late, related study on China has gradually gained significance until recent years. The summary of the literature on HSR' impact on economic growth is shown in Appendix A. In reality, China's HSR development and policy differ from those of other countries, and there is a knowledge gap that applies to China's HSR. Few analyses of China's HSR system take into consideration industry heterogeneity, which is the focus of research on industrial structure issues. Chandra and Thompson [6] found that certain industries profit from US interstates because of lower transportation costs, while others have migrated as a result of economic activity [6]. Holl [7] studied the effects of road investment and the aggregation effect on enterprises in 13 industrial and 9 service sectors in Portugal, and found significant differences across industries [7]. Western research material and methodologies about economic effects of HSR are numerous since it was the first to realize the industrial revolution [8–10]. Chen and Silva [11], Ahlfeldt and Feddersen [12], Chen and Haynes [13], Guirao et al. [14], Guirao et al. [15], Cascetta et al. [16] studied the impact of HSR's opening in Spain, German, China, France and Italy, and the positive impact is acknowledged. The recent papers on the economic consequences of HSR concentrate on individual industries and production factors including regional labor mobility, economic development, and urbanization [17–20]. Zheng et al. [21] and Pan et al. [22] measured the spatial spillover effect of HSR stations in China, and found that HSR spur the agglomeration of various economic activities from being near and far from the station. About empirical methods, DID (Differences-in-Differences) model is used widely. Wang et al. [23] used anti-gravity and gravity bias models to study how the urban structure of the Yangtze River Delta evolved after the opening of the HSR. Liu et al. [24] used a time-varying DID model to study the spatial integration and industrial development of the Yangtze River Economic Belt, and explained the relationship between the spatial integration of urban aggregations and the characteristics of industrial development after the opening of the HSR. Liang et al. [25] and Wang et al. [28] used the PSM-DID model to analyze the economic development along the HSR line based on the panel data of prefecture-level cities. Li et al. [26] used synthetic control methods (SCM) to investigate the economic effect of HSR, and the results show that the economic effect of HSR had strong disparity [26]. Li et al. [27] used both the DID model and threshold regression and found that the opening of HSR had a significant threshold effect on improving the efficiency of the service sector [27]. Meng et al. [29] constructs an HSR operation network (HSRON) model to study the impact of network position (NP) on service industry agglomeration (SIA) by employing complex network analysis and panel regression methods [29]. Melo et al. [30] discovered that estimates of transportation infrastructure's productivity impact differed by major industry groups, with estimates for the US economy averaging higher than estimates for European countries, and estimates for highways averaging higher than estimates for other modes of transportation [30]. In the empirical analysis on HSR in China, there have been few papers focus on the quantification of transportation costs. It becomes clear that a well-established theoretical framework for analyzing the impact of HSR in China is desperately required. This paper is devoted to a more in-depth assessment of conditions based on previous research.

The contribution of this paper is to improve the theoretical and empirical framework regarding the economic impact of HSR in China on the basis of previous papers. On the one hand, the mathematical economic geography theory of the impact of the opening of the HSR on the industrial structure was proposed, which comprehensively complemented the hypotheses on the economic effects of HSR. The empirical analysis, on the other hand, was in line with the reality in China. In contrast to other studies, we chose appropriate control and treatment groups to avoid cross-influence of lines within the area. In addition to verifying the hypotheses, the mechanism and heterogeneity of HSR on the industrial structure were explored, revealing the manifestations of economic transformation in China.

The remainder of this paper is structured as follows. Section 2 presents the theoretical framework. Section 3 describes the data set. Our empirical results are presented in Sect. 4. Our main conclusions are then summarized in Sect. 5.

2 Theoretical and Analytical Framework

The enhancement of accessibility is a direct result of the opening of HSR [10, 31]. In addition to decreasing distances in time and space, the HSR indirectly increases the flow of factors such as labor, social capital, and technology, thereby reshaping the market structure [1, 5]. Moreover, the opening of HSR facilitates the establishment of economies of scale, which further alters market competition patterns, as seen by the clustering of urban tertiary sectors and the expansion of cities not on the route [8, 32]. The rationality of the industrial structure will be influenced by the advancement of the industrial structure [14]. As the cycle progresses, the advantageous industries will cluster, and the industrial structure will shift as well, both of which are manifestations of indirect impacts. The impact of the introduction of HSR on the industrial structure is seen in Fig. 3.

The theories and hypotheses proposed in this paper for the impact of HSR on the industrial structure are built using the core–periphery concept. [1] Area A and area B are the two economic zones. Assume there are no costs or restrictions to labor mobility in both places; consumers are rational, and they consume tradable product x and product y to maximize their utility with wages.

$$U_A = C_{Ax}^{u} C_{Ay}^{1-u} \tag{1}$$

$$S.t. P_{Ax}C_{Ax} + P_{Ay}C_{Ay} = W_A \tag{2}$$

where $0 < \mu < 1 < \sigma$, C_{Ax} is the product x consumed in area A, C_{Ay} is the product y consumed in area A. P_{Ax} and P_{Ay} are the corresponding prices, following the form of the D-S model. C_{Ax} is expressed by constant elasticity of substitution (CES). W_A is a consumer's income in area A. If consumer indifference curves are continuous, then:

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[1] The core–periphery model is based on Nobel laureate Krugman's Dixit-Stiglitz (D-S) model, which first proposed that the link between transportation costs and economies of scale is the basis of industrial agglomeration in 1991.

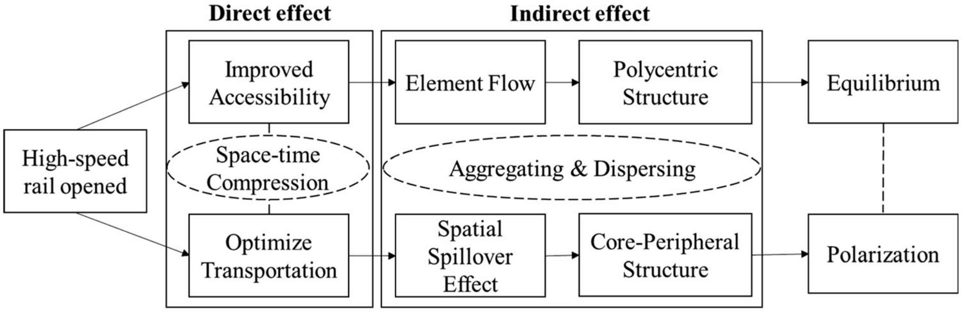


Fig. 3 The direct and indirect effect of the opening of HSR on the industrial structure

$$C_{Ax} = \left(\int_0^n c_{Ai}^{1-(1/\sigma)} d_i\right)^{1/(1-1/\sigma)} \tag{3}$$

$$P_{Ax} = \left(p_i^{1-\sigma} d_i\right)^{(1-\sigma)} \tag{4}$$

where p_i is the price of the i-th product. After optimization, the indirect utility function is:

$$V_A = \mu^{\mu}(1-\mu)^{1-\mu} W_A / \left(P_{Ax}^{\mu} P_{Ay}^{1-\mu}\right) \tag{5}$$

where μ is the payment's share for the i-th product. With the optimization conditions of suppliers, we define W_B to be the income of consumers in area B, and s_n to be the proportion of product x in area A among all product x ($S_n = n_i/n$ where n is the total of x). This paper introduces the theory of "iceberg transportation cost" proposed by Samuelson, which holds that there is a cost, represented by T, and only $1/T(1/T < 1)$ of products can be reached in the process of transporting products from area A to area B. Then, (4) can be transformed into the following:

$$P_{Ax} = \left[s_n W_A^{1-\sigma} + (1-s_n)(W_B T)^{1-\sigma}\right]^{1/(1-\sigma)} \tag{6}$$

where σ is the elasticity of substitution, and T is the product's transportation cost between area A and area B. Substituting (6) into (5), we get:

$$\begin{aligned} V_A = \mu^{\mu}(1-\mu)^{1-\mu} W_A / P_{Ay}^{1-\mu}[s_n W_A^{1-\sigma} + (1 \\ - s_n)(W_B T)^{1-\sigma}]^{\alpha} \end{aligned} \tag{7}$$

where $\alpha = \mu/(\sigma - 1)$, similarly, we get:

$$\begin{aligned} V_B = \mu^{\mu}(1-\mu)^{1-\mu} W_B / P_{By}^{1-\mu}[s_n (W_A T)^{1-\sigma} + (1 \\ - s_n)(W_B)^{1-\sigma}]^{\alpha} \end{aligned} \tag{8}$$

The "accessibility" between locations has improved after the opening of the HSR. Assume $T = e^{\tau \times t(H)}$, where H is a dummy variable for whether HSR is opened, τ is time attenuation, and t is the average travel time from area A to area B after the opening of HSR. According to the location selection of the long-term equilibrium, the comparative utility function is as follows:

$$\begin{aligned} S_{AB} &= \frac{V_A}{V_B} \\ &= \frac{W_A}{W_B}\left(\frac{P_{Ay}}{P_{By}}\right)^{\mu-1}\left[\frac{s_n W_A^{1-\sigma} + (1-s_n)\left(W_B e^{\tau \times t(H)}\right)^{1-\sigma}}{s_n\left(W_A e^{\tau \times t(H)}\right)^{1-\sigma} + (1-s_n) W_B^{1-\sigma}}\right]^{-\alpha} \\ &= \left[\frac{\frac{s_n}{1-s_n}\left(\frac{W_A}{W_B}\right)^{1-\sigma} + \left[e^{\tau \times t(H)}\right]^{1-\sigma}}{\frac{s_n}{1-s_n}\left(\frac{W_A}{W_B} e^{\tau \times t(H)}\right)^{1-\sigma} + 1}\right]^{-\alpha} \end{aligned} \tag{9}$$

Note $\left(e^{\tau \times t(H)}\right)^{\alpha\sigma - \alpha} = \lambda$. If we substitute the bivariable Taylor series expansion of $\frac{s_n}{1-s_n}$, $\frac{W_A}{W_B}$ and $ln[1 - \frac{\alpha}{\lambda}(1 - \lambda^2)\frac{s_n}{1-s_n}]$ into (9) and take the logarithm, we get:

$$lnS_{AB} = ln\frac{W_A}{W_B} + (\mu - 1)ln\frac{P_{Ay}}{P_{By}} - \alpha ln\lambda - \frac{\alpha}{\lambda}(1 - \lambda^2)\frac{s_n}{1-s_n} \tag{10}$$

The consumer utilities in two areas are equal in the long-term equilibrium, that is:

$$S_{AB} = \frac{V_A}{V_B} = 1,\ lnS_{AB} = 0 \tag{11}$$

Note $\frac{S_n}{1-S_n} = S$, then we get:

$$\begin{aligned} S &= \frac{s_n}{1-s_n} \\ &= -\frac{\lambda}{1-\lambda^2} ln\lambda + \frac{\lambda}{\alpha(1-\lambda^2)} ln\frac{W_A}{W_B} + \frac{\lambda(\mu-1)}{\alpha(1-\lambda^2)} ln\frac{P_{Ay}}{P_{By}} \end{aligned} \tag{12}$$

$\frac{\partial S}{\partial H}$ is the impact of HSR on the industrial structure. Take the derivative of (12) with respect to H:

$$\frac{\partial S}{\partial H} = \frac{\partial \lambda}{\partial H}\left\{(1 - 3\lambda^2)[ln\frac{W_A}{W_B} + (1-\mu)ln\frac{P_{Ay}}{P_{By}}]/\alpha + \frac{\lambda^2 - 1 - ln\lambda - \lambda^2 ln\lambda}{(\lambda^2 - 1)^2}\right\} \tag{13}$$

It can be concluded that $0 < \frac{\partial \lambda}{\partial H} < 1$. $\frac{\partial S}{\partial H}$ can be determined by (13).

$$\begin{aligned} &\text{While } \lambda \to 0^{+} && \frac{\partial S}{\partial H} > 0 \\ &\text{While } \lambda \to 1/\sqrt{3} && \frac{\partial S}{\partial H} > 0 \\ &\text{While } \lambda \to 1^{-} && \frac{\partial S}{\partial H} > 0 \end{aligned} \tag{14}$$

If $\frac{\partial S}{\partial H} > 0$, the behavior is "aggregation," but if $\frac{\partial S}{\partial H} < 0$ then behaves as "dispersion." Calculate the second derivative of (12) as follows:

$$\frac{\partial^2 S}{\partial H^2} = \left(\frac{\partial \lambda}{\partial H}\right)^2 \left\{ \frac{-6\lambda}{\alpha}\left[ln\frac{W_A}{W_B} + (1-\mu)ln\frac{P_{Ay}}{P_{By}}\right] - \frac{-4\lambda(\lambda^2 - 1 - ln\lambda - \lambda^2 ln\lambda)}{(\lambda^2-1)^3} + \frac{2\lambda - 2\lambda ln\lambda - \lambda - 1/\lambda}{(\lambda^2-1)^2} \right\} \tag{15}$$

It is not difficult to determine that $\frac{-4\lambda(\lambda^2-1-ln\lambda-\lambda^2 ln\lambda)}{(\lambda^2-1)^3}$ and $\frac{2\lambda-2\lambda ln\lambda-\lambda-1/\lambda}{(\lambda^2-1)^2}$ are always negative within the domain. Next, we conclude the following:

(1) $[ln\frac{W_A}{W_B} + (1-\mu)ln\frac{P_{Ay}}{P_{By}}] > 0$, then $\frac{\partial^2 S}{\partial H^2} < 0, \forall \lambda \in (0,1)$ and $\frac{\partial S}{\partial H} > 0, \forall \lambda \in (0,1)$. Fig. 4a shows that the opening of the HSR can boost the number of industries, but the pace of growth will slow at the periphery.

(2) $[ln\frac{W_A}{W_B} + (1-\mu)ln\frac{P_{Ay}}{P_{By}}] \le 0$. Fig. 4b shows $\frac{\partial^2 S}{\partial H^2} < 0$ at the beginning, $\frac{\partial^2 S}{\partial H^2} > 0$ at the end, and only one zero point. There are two possible situations. Within the domain, $\partial S/\partial H > 0$ is identical. The HSR is always in an "aggregating state" when it is opened; the pace of aggregation, however, varies. (2) $\partial S/\partial H > 0$ is observed. The aggregation effect of the HSR improves with time until it reaches its peak. The dispersion effect comes later, forcing suppliers with lower competitiveness to migrate to the outskirts. Finally, industries pool their resources to establish higher-quality tertiary industrial conglomerates.

The following hypotheses are proposed according to the derivation:

Hypothesis I: Once the HSR opens, the number of tertiary industry businesses will increase and higher-grade industries will continue to aggregate. In the short term, it encourages tertiary industry aggregation in cities along the route, but in the long run, the aggregation is dependent on the initial circumstances.

Hypothesis II: Once the HSR opens, the industrial structure advances steadily, resulting in a structural shift in the tertiary industry, from basic to advanced sectors.

3 Data

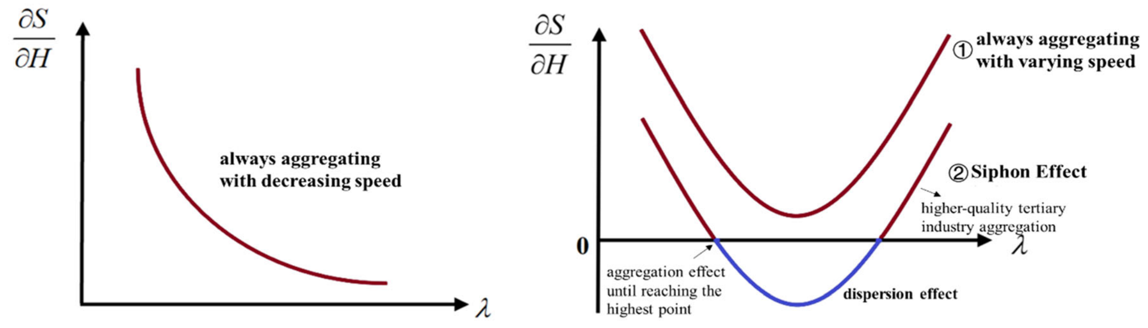
3.1 Objects

This paper chooses Beijing–Shanghai and Beijing–Guangzhou HSR as the objects (see Appendix B for details). On the one hand, they are being built at an early stage. The Beijing–Shanghai HSR is China's first dedicated long-distance passenger route, and it goes through some of China's most densely inhabited and economically developed districts. The Beijing–Guangzhou HSR is a watershed moment in China's HSR development and the world's longest HSR. Their construction, on the other hand, is rather quick, which helps to eliminate cross-effects caused by other factors. The Beijing–Shanghai and Beijing–Guangzhou HSR run through a total of 131 prefecture-level cities and municipalities. We omitted cities with other HSR lines passing through, prefecture-level cities that were demoted and divided during the sample period, such as Chaohu, cities with poor accessible data, such as Enshi and Shennongjia forest area, and so on in order to obtain unbiased estimates. The control group consists of 40 cities, with a total of 82 prefecture-level cities as samples.

3.2 Variables

3.2.1 Dependent Variable

The dependent variables are the location entropy of the tertiary industry (LQ_third), the rationalization of



(a)Decreasing-speed aggregation (b)U-shaped-speed aggregation

Fig. 4 Forms of industrial aggregation and diffusion of HSR industrial structure (SR) and the advancement of industrial structure (SA). Location entropy is a commonly used index to measure the distribution of elements, and the location entropy of industry i in area j in the country (LQ_{ij}) is as follows:

$$\mathrm{LQ}_{ij} = \frac{q_{ij}/q_j}{q_i/q} \tag{16}$$

where q_{ij} is the indicator of industry i in area j, q is the indicator of all industries in the country; q_j is the indicator of all industries in area j; q_i is the indicator of industry i in the country. The larger the LQ_{ij} value, the higher the aggregation degree of the tertiary industry, implying that industry i has a competitive advantage in area j.

The advancement of the industrial structure (SA) is affected by multiple factors, and its definition is currently neither standard nor rigid. We generated an index to quantify SA using the molar structure change value calculation technique. A set of three-dimensional vectors $X_0 = (x_{1,0}, x_{2,0}, x_{3,0})$ is constructed using the share of three industries in GDP as the spatial vector. The angles between X_0 and $X_1 = (1,0,0)$, X_0 and $X_2 = (0,1,0)$, X_0 and $X_3 = (0,0,1)$ are, respectively, θ_1, θ_2 and θ_3.

$$\theta_j = \arccos\left[\frac{\sum_{i=1}^{3}\left(x_{i,j}\cdot x_{i,0}\right)}{\left(\sum_{i=1}^{3} x_{i,j}^2\right)^{\frac{1}{2}} \cdot \left(\sum_{i=1}^{3} x_{i,0}^2\right)^{\frac{1}{2}}}\right] \tag{17}$$

SA is thus defined as follows:

$$SA = \sum_{i=1}^{3}\sum_{j=1}^{3}\theta_j \tag{18}$$

The rationalization of the industrial structure (SR) measures whether the proportion of industries is appropriate. The following is a regularly used measuring form for assigning weights to the significance of each of the three industries:

$$\begin{aligned}\mathrm{SR} &= \sum_{i=1}^{n}\left(\frac{\mathrm{GDP}_i}{GDP}\right)\left|\frac{GDP_i/L_i}{GDP/L} - 1\right| \\ &= \sum_{i=1}^{n}\left(\frac{GDP_i}{GDP}\right)\left|\frac{GDP_i/GDP}{L_i/L} - 1\right|\end{aligned} \tag{19}$$

where GDP is the city's gross product, GDP_i/L_i is labor productivity, GDP_i/GDP is the output structure, and L_i/L is the industry structure. Primary, secondary, and tertiary industries are represented by $i = 1,2,3$. The industrial structure deviation is 0 when the output structure matches the employment structure, which is the most appropriate situation. It should be noted that the lower this ratio is, the more the industrial structure has been rationalized.

3.2.2 *Independent Variable*

The treatment group ($treated_c$, set to 1) is cities along the HSR, whereas the control group ($controlled_c$, set to 0) is cities outside the HSR. There is also a time dummy variable, which is 0 before the HSR's opening or 1 after the HSR's opening. The core independent variable HSR_i is the interaction term of the product of the aforementioned two. The Beijing–Shanghai HSR was opened in 2011, with data from 2001 to 2010 as pre-opening data, and data from 2011 to 2017 as post-opening data. The Beijing–Wuhan segment of the Beijing–Guangzhou HSR opened in 2012, while the Wuhan-Guangzhou section opened in 2009. The Beijing–Guangzhou HSR is valued in the same manner. The particular expression is as follows:

$$Y_{it} = \beta_0 + \beta_1 HSR_{it} + \beta_2 X_{it} + Z_i + year_i + \varepsilon_{it} \tag{20}$$

where Z_i denotes the city-level fixed effects that do not change over time, X_{it} are the time-varying control variables, and ε_{it} is the residual term. The difference induced by HSR is represented by β_1, and the difference between cities is represented by β_2.

4 Summary Statistics

Openness (*lfdi*), Economy (*lgdp_average*), Wage (*lwage_average*), Government interference (*lfee*), Human capital (*lhuman_capital*), Informatization (*ltele_pop*, Transportation (*lroad_average*) and Infrastructure (*lbooks_average* and *lhospital_num*) are the control variables. The sample period is 2003–2017, and the data come from the *China City Statistical Yearbook* and the *China Statistical Yearbook*. We use the logarithm of the data throughout the paper and provide the summary descriptive statistics in Table 1. Obviously, with the opening of the HSR, the location entropy of the tertiary industry and the advancement and rationalization of industrial structure are greater, and more empirical study is necessary.

5 Empirical Strategy

5.1 Time-Varying DID Regression

5.1.1 *Parallel Trend Test*

The parallel trend test, as described by Shao [17], is used to determine whether trends in the treatment and control groups are consistent:

Table 1 Descriptive statistics

Variables	Total			Treated cities		Controlled cities	
	Observations	Mean	S.D.	Mean	S.D.	Mean	S.D.
HSR	1230	0.2425	0.4288	1.0000	0.0000	0.0000	0.0000
LQ_third	1230	0.8103	0.1986	0.8424	0.2242	0.8001	0.1887
SA	1230	2.2371	0.1451	2.3219	0.1598	2.2100	0.1289
SR	1230	5.3085	10.6754	6.9407	13.9910	4.7866	9.3205
lgdp_average	1230	10.0918	0.8761	10.7132	0.8612	9.8931	0.7833
lfdi	1230	10.4005	1.5113	11.4537	1.3642	10.0637	1.3975
lwage_average	1226	10.5730	1.3046	10.9556	0.7858	10.4507	1.4099
lfee	1230	14.2746	1.1465	15.2789	0.9090	13.9539	1.0226
lhuman_capital	1230	15.6712	0.6365	15.8623	0.6311	15.6090	0.6255
lroad_average	1216	0.9298	0.8593	1.3325	0.8374	0.8014	0.8263
ltele_pop	1230	8.0011	3.6456	6.3125	0.8152	8.5410	4.0160
lbooks_average	1228	-1.4620	1.0909	-1.1782	1.2986	-1.5548	0.9999
lhospital_num	1228	5.1989	0.5905	5.3315	0.5730	5.1566	0.5900

$$Y_{it} = \beta_0 + \sum\nolimits_{m=1}^{3} \beta_m FirstHSR_{i,t-m} + \sum\nolimits_{n=0}^{5} \beta_n FirstHSR_{i,t+n} + \beta_2 X_{it} + Z_i + year_t + \varepsilon_{it} \tag{21}$$

where t is the first HSR year of operation. The year before the opening is $m(m = 1, 2, 3)$, while the year following is $n(n = 0, 1, 2, 3, 4, 5)$. $FirstHSR_{i,t}$, $FirstHSR_{i,t-m}$, $FirstHSR_{i,t+n}$ are dummy variables that return 1 if city i 's HSR is operational in the specified year. The initial 4 years $(year = -4, -3, -2, -1)$ and the latter 4 years $(year = 5, 6, 7, 8)$ x are both significant, as shown in Fig. 5. As a result, the opening of HSR has a large delayed impact on the aggregation of tertiary industries, and this conclusion is consistent with Shao [17]. And before $year = 4$, β_m increases year by year, which can be explained by the fact that the corporation made strategic planning after getting the news ahead of time [5, 33]. It may be inferred that there is no significant difference in trend between the treatment and control groups before HSR's opening. By repeating the steps, it is confirmed that both industrial structure advancement and rationalization satisfy the hypothesis of a parallel trend.

5.1.2 Baseline Regression

The opening of *HSR* can be regarded as a quasi-natural experiment.[2] [3] Multi-period DID is used as the identification model, in the form:

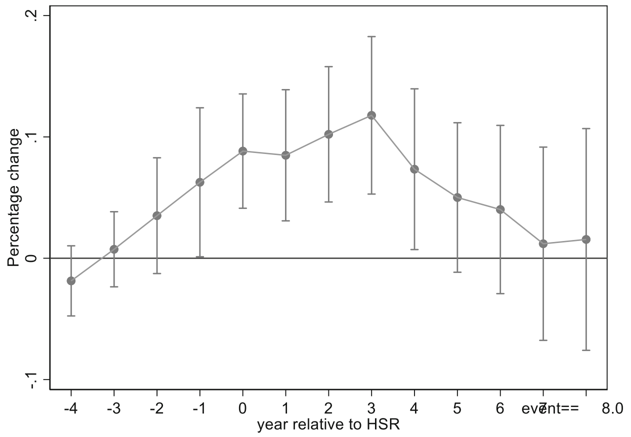


Fig. 5 The parallel trend test of ***LQ_third***

$$Y = \beta_0 + \delta_0 du + \beta_1 dt + \delta_1 du \cdot dt + \varepsilon_{it} \tag{22}$$

where du is the entity fixed effect. dt is the time fixed effect. δ_1 is the coefficient of double differences, which is also the value of interest in this paper. The coefficients of *HSR* remain significant and positive when control variables from models (1) to (6) are included in Table 2. Specifically, ceteris paribus, *LQ_third* and *SA* increased by 0.029 and 0.021 respectively after *HSR* opened. This supports Hypothesis I and Hypothesis II of this paper, namely, that the *HSR* has a significant positive impact on tertiary industry aggregation and industrial structure advancement.

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[2] According to the principles of China's railway network planning, the location of *HSR* is determined by the "natural force" of the geographical location, the "government force" of the *HSR* strategic planning, and the competition and cooperation of local governments and the "market force" of the first-mover advantage of developed

Footnote 2 continued
regions. As a result, local governments have little control in whether HSR lines go through their jurisdictions.

[3] A series of tests shown in Appendix C conducted before regression revealed no multicollinearity, heteroscedasticity, or model identification error.

Table 2 Regression results of LQ_third, SR, and SA

Variables	(1) *LQ_third*	(2) *LQ_third*	(3) *SA*	(4) *SA*	(5) *SR*	(6) *SR*
HSR	0.013*	0.029***	0.041***	0.021***	2.718***	3.077***
	(1.74)	(3.84)	(8.00)	(4.40)	(3.18)	(3.19)
lgdp_average	−0.031***	−0.046***	0.042***	0.038***	1.094*	0.717
	(−5.05)	(−4.82)	(7.74)	(5.19)	(1.94)	(0.77)
lwage_average	0.025***	0.029***	0.003***	0.000	0.090	0.110
	(14.16)	(15.86)	(3.48)	(0.67)	(0.51)	(0.65)
lfdi	−0.017***	−0.013***	0.007***	0.004**	0.963***	0.887***
	(−5.83)	(−4.57)	(3.57)	(2.03)	(3.53)	(3.20)
lhuman_capital	0.051**	0.035	−0.024	−0.023	−4.672***	−3.925***
	(2.11)	(1.53)	(−1.63)	(−1.61)	(−3.40)	(−2.74)
fee		0.000		0.000***		−0.000***
		(0.28)		(5.08)		(−3.61)
lroad_average		−0.022***		0.019***		2.624***
		(−2.71)		(3.09)		(2.59)
ltele_pop		0.001		−0.002***		−0.004
		(0.96)		(−3.68)		(−0.05)
lbooks_average		0.034***		−0.020***		−1.256**
		(7.05)		(−6.39)		(−1.97)
lhospital_num		0.015		−0.009*		3.216**
		(1.47)		(−1.79)		(2.48)
Constant	0.225	0.538	2.067***	2.172***	55.863**	27.983
	(0.55)	(1.32)	(8.22)	(8.42)	(2.27)	(1.05)
City fixed	Yes	Yes	Yes	Yes	Yes	Yes
Time fixed	Yes	Yes	Yes	Yes	Yes	Yes
Observations	1,226	1,209	1,226	1,209	1,226	1,209
R-squared	0.847	0.861	0.893	0.911	0.445	0.452

Note: *, **, and *** indicate significant levels at 10%, 5%, and 1%, respectively

The deviation from equilibrium in industrial structure is shown by the significant positive coefficient of *SR*. The findings also show that the opening of the *HSR* causes an imbalance in the local industrial structure and a lack of coordination in resource allocation. Wang (2019) studied the Yangtze River Delta region and discovered that HSR boosted the proportion of tertiary industry added value and improved the quality of urbanization by stimulating industrial structure upgrading [21]. Liang (2020) performed research on the Guangdong–Guangxi–Guizhou HSR and discovered that by altering the industrial structure of the area, the HSR may promote the development of undeveloped regions [25]. Wang (2019) and Liang (2020) came to similar conclusions as this paper's findings.

5.2 Robustness Test

5.2.1 Changes in the Sample

The robustness test includes sample change, instrumental variables, and a placebo test. The changes in the sample come from adjusting the period scope [Model (1) to (3)] and excluding provincial capitals and municipalities [Model (4) to (6)]. The *HSR* coefficients remain significantly positive in Table 3, except for model (5)[4]. Model (5)'s insignificance might be due to endogenous recognition across cities, and a heterogeneous effect will be discussed later. As a result, the positive effect of *HSR* is consistent across samples, and the conclusion in this paper is robust.

5.2.2 Instrumental Variables (IV)

To test for endogeneity owing to omitted variables, instrumental variables (IV) was used in this paper. The IV of transportation infrastructure commonly mentioned in previous papers are landslides, geographic slope, ancient postal services and historical passenger traffic, historical planning information, and so on [34–36]. Referred to Dong

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[4] The finding is still robust ($P>|t|=0.125$) if the significance level is increased to 20%.

Table 3 Robustness test in sample changes

Variables	(1) LQ_third	(2) SA	(3) SR	(4) LQ_third	(5) SA	(6) SR
	Reduce the bandwidth			Delete provincial capitals and municipalities		
HSR	0.023***	0.014***	2.513**	0.022***	0.011	3.490***
	(2.95)	(3.11)	(2.44)	(2.85)	(1.54)	(2.95)
lgdp_average	0.003	0.057***	1.632**	−0.037***	0.034***	1.357
	(0.27)	(7.05)	(2.12)	(−3.78)	(3.61)	(1.25)
lwage_average	0.029***	−0.000	0.087	0.026***	−0.001	0.094
	(18.55)	(−0.58)	(0.59)	(15.02)	(−1.01)	(0.48)
lfdi	−0.013***	−0.000	0.518*	−0.013***	0.002	0.950***
	(−4.29)	(−0.16)	(1.85)	(−4.31)	(1.34)	(3.11)
lhuman_capital	0.062**	−0.019	−3.131*	0.082***	0.002	−1.828
	(2.21)	(−1.17)	(−1.71)	(3.28)	(0.17)	(−0.90)
fee	0.000	0.000***	−0.000***	0.000***	0.000***	−0.000
	(1.49)	(4.94)	(−3.09)	(3.70)	(4.01)	(−0.93)
lroad_average	−0.009	−0.017**	−0.277	−0.030***	0.002	2.688**
	(−0.84)	(−2.37)	(−0.30)	(−3.42)	(0.32)	(2.42)
ltele_pop	−0.000	−0.001*	0.060	0.002*	−0.001***	0.028
	(−0.47)	(−1.96)	(0.67)	(1.67)	(−2.87)	(0.30)
lbooks_average	0.002	−0.009**	1.619*	0.031***	−0.017***	−1.733**
	(0.22)	(−2.10)	(1.72)	(5.85)	(−3.97)	(−2.13)
lhospital_num	−0.014	0.001	6.144***	0.019*	−0.008	3.970**
	(−1.39)	(0.13)	(3.30)	(1.67)	(−1.37)	(2.57)
Constant	−0.294	1.953***	0.954	−0.341	1.793***	−15.811
	(−0.59)	(6.43)	(0.03)	(−0.78)	(6.35)	(−0.43)
City fixed	Yes	Yes	Yes	Yes	Yes	Yes
Time fixed	Yes	Yes	Yes	Yes	Yes	Yes
Observations	889	889	889	1063	1063	1063
R-squared	0.900	0.943	0.511	0.764	0.860	0.446

Note: *, **, and *** indicate significant levels at 10%, 5%, and 1%, respectively

[18], this paper uses China's historical railway network in 1961 as the IV of the opening of the HSR. The Beijing–Shanghai and Beijing–Guangzhou HSR construction is based on the railways constructed in 1961, and railways built in 1961 have no direct impact on the present industrial structure. Exogeneity and correlation are both satisfied using the railway network in 1961 as IV. The results in Table 4 show that the significant effect of *HSR* on *SH* is 0.0822, which is consistent with the baseline regression in Table 2. The correlation between instrumental and explanatory variables is also verified (*old_railway* on *HSR* is 0.2198), and the assumption of weak instrumental variables was rejected ($F - \text{Statistic} > 10$).

5.2.3 Placebo Test

To ensure that the results are not the result of chance or randomness, a placebo test is utilized, in which the treatment group is generated at random. The estimated coefficient of interaction in (22) is as follows:

$$\widehat{\beta}_1 = \beta_1 + \gamma \frac{cov(treated_c \times time_t, \varepsilon_{ct}|z)}{var(treated_c \times time_t|z)} \tag{23}$$

where z is the control variables. When $\gamma = 0$, the estimator $\widehat{\beta}_1$ is unbiased. If $treated_c \times time_t$ is replaced by other variables that do not affect explained variables ($\beta_1 = 0$), and $\widehat{\beta}_1 = 0$ is obtained by estimation, then $\gamma = 0$ can be realized. Following this line of reasoning, we make the event of the opening of *HSR* random, so it has no effect on LQ_third_{ct}, SA_{ct} and SR_{ct}, i.e., $\beta^{random} = 0$. The distribution of $\widehat{\beta}^{random}$ is obtained by repeating the above preceding technique as shown in Fig. 6, and *t*-statistics are distributed U-shaped, with peaks around zero.

5.3 Heterogeneity Test

5.3.1 Socioeconomic Characteristics Among Cities

The effect of HSR is varied across different regions due to differences in endowment [37–39]. This paper takes 3

Table 4 Generalized method of moments for instrumental variables

Variables	2SLS *SA*	First stage *HSR*
old_railway		0.2198*** (0.0273)
HSR	0.0822*** (0.0256)	
Variable control	Yes	Yes
Observations	1,209	1,209
Adjusted R-squared		0.3204
F-statistics		57.96

Note: *, **, and *** indicate significant levels at 10%, 5%, and 1%, respectively

million people and 0.5 million people per square kilometer as the classification for city size and population density, respectively. [5] Table 5 shows that the economic effects of metropolises and cities with low population density are statistically more significant than those of other cities, implying a link between socioeconomic characteristics and the impact of *HSR* on the industrial structure. This is to be expected, since megacities and cities with low population density have better market conditions and a greater effect on factor flows, making them more likely to achieve industrialization and structural upgrading.

5.3.2 Spillover and Aggregation Effects Across Industries

The spatial weight matrix is used to determine the spatial correlation by whether two economic units are geographically located adjacent to each other. With the modernization of transportation infrastructure, this paper uses the queen adjacency matrix to generate an 82*82 adjacency matrix (w_{ij}). The spatial matrix and Moran's I are expressed as follows:

$$w_{ij} = \begin{cases} 1 & \text{area } i \text{ is adjacent to } j \\ 0 & \text{area } i \text{ is adjacent to } j \text{ or } i = j \end{cases} \tag{24}$$

$$Moran'sI = \frac{\sum_{i=1}^{n}\sum_{j=1}^{n} W_{ij}(x_i - x_m)(x_j - x_m) / \sum_{i=1}^{n}\sum_{j=1}^{m} W_{ij}}{\sum_{i=1}^{n}(x_i - x_m)^2 / n} \tag{25}$$

where x_i is the value of unit i, x_j is the value of unit j, x_m is the average value of the grid cells in the area, n is the total number of cell grids, and W_{ij} is the spatial weight matrix. *Z (Moran's I)* is used to test the significance of *Moran's I*, and the null hypothesis is that there is no spatial autocorrelation.

$$Z(Moran'sI) = \frac{Moran'sI - E(Moran'sI)}{\sqrt{Var(Moran'sI)}} \tag{26}$$

Moran's I was calculated for 18 subsectors except for agriculture, forestry, animal husbandry, and fishery, and the results and *Industry Classification Standard* are shown in. Despite the fact that the majority of the LQ_X in the sample is not statistically significant at the 1% level each year, the spatial correlation is still worth researching given the delayed impact of the *HSR* opening seen in Fig. 5. [6] According to the results of the spatial autocorrelation test, this paper obtains the spatially relevant industries as follows: mining (LQ_2), electricity, gas, and water production and supply (LQ_4), transportation warehousing and postal (LQ_7), accommodation and catering (LQ_8), financial (LQ_{10}), real estate (LQ_{11}), scientific research and technical services (LQ_{13}), education (LQ_{16}), health and social security (LQ_{17}) and public management and social organizations (LQ_{19}).

Spatial lag models (SAR), spatial error models (SEM), and spatial Durbin models (SDM) are examples of spatial econometric models. SAR and SEM assume spatial autocorrelation between dependent variables and error terms, respectively, whereas SDM considers both. To obtain SAR and SEM, the Kronecker product is employed to integrate the spatial matrix across time. The following are their expressions:

Spatial lag model (SAR):

$$Y_{it} = \beta_0 + \rho W_{ij} Y_{it} + \beta X_{it} + \alpha_i + \gamma_t + \varepsilon_{it} \tag{27}$$

Spatial error model (SEM):

$$Y_{it} = \beta_0 + \beta X_{it} + \alpha_i + \gamma_t + \mu_{it}, \mu_{it} = \lambda W_{ij} + \varepsilon_{it} \tag{28}$$

Spatial Durbin model (SDM):

$$Y_{it} = \beta_0 + \rho W_{ij} Y_{it} + \theta W_{ij} Y_{it} + \beta X_{it} + \alpha_i + \gamma_t + \varepsilon_{it} \tag{29}$$

where β_0 is a constant, β is the matrix of the variable coefficients, X is the matrix of the independent variables, and W_{ij} is the weight matrix. ρ is the spatial autoregressive coefficient, λ is the spatial autocorrelation coefficient, and θ is the spatial spillover effect. α_i and γ_t are used to measure spatial fixed effects and time fixed effects, respectively. ε_{it} is the error term that is subject to normal distribution. This paper uses the approach described by Pace (2009) to separate the estimation of direct and indirect effects from SAR and SDM [40], and it takes the following form:

$$Y_{it} = (I - \rho W_{ij})^{-1}(\beta X_{it} - W_{ij}) X_{it}\theta + (I - \rho W_{ij})^{-1}\alpha_i + (I - \rho W_{ij})^{-1}\lambda_i + (I - \rho W_{ij})^{-1}\zeta_{it} \tag{30}$$

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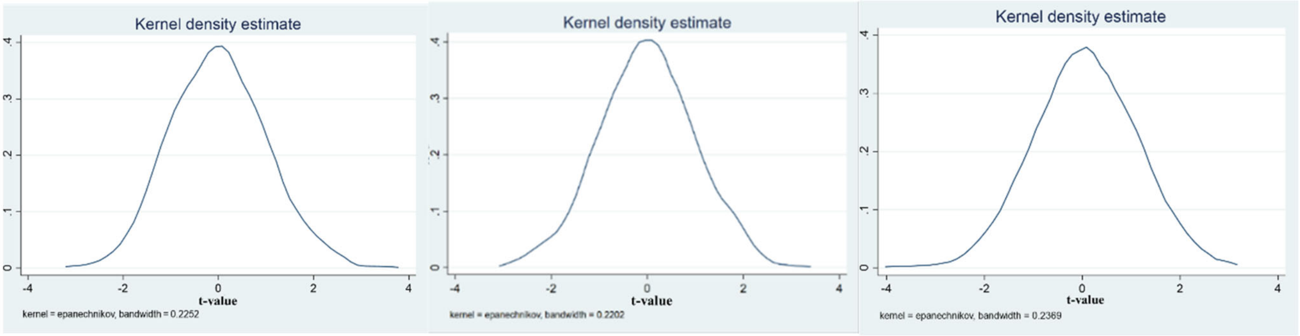
[5] The reference is the scale classification standard of the State Council of China for large cities (type I) and small and medium-sized cities (type II), and the population density standard of the State Council of China for the construction of metro cities.

[6] The economic effects of the high-speed rail's opening are numerous, but it is impossible to cover everything at this time. We correctly decrease the significance limit to 20% and delete Moran's I insignificant indications.



(a) LQ_third **(b) SA** **(c) SR**

Fig. 6 Placebo test of LQ_third, SA and SR

Table 5 Heterogeneity test of socioeconomic characteristics among cities

Variables	(1) *LQ_third*	(2) *SA*	(3) *SR*	(4) *LQ_third*	(5) *SA*	(6) *SR*
	Megalopolis			Small and medium-sized cities		
HSR	0.027***	0.016***	1.535**	0.051*	−0.002	14.403***
	(3.16)	(3.25)	(2.16)	(1.96)	(−0.13)	(2.94)
Observations	1,017	1,017	1,017	192	192	192
Adjusted R-squared	0.852	0.915	0.454	0.908	0.920	0.510
Variables	(7) *LQ_third*	(8) *SA*	(9) *SR*	(10) *LQ_third*	(11) *SA*	(12) *SR*
	Density>0.05			Density <=0.05		
HSR	0.034***	0.017***	3.038***	0.029*	0.013***	2.122
	(3.50)	(3.06)	(2.77)	(1.77)	(1.51)	(1.41)
Observations	794	794	794	415	415	415
Adjusted R-squared	0.888	0.929	0.482	0.788	0.842	0.419
Variable control	Yes	Yes	Yes	Yes	Yes	Yes
City fixed	Yes	Yes	Yes	Yes	Yes	Yes
Time fixed	Yes	Yes	Yes	Yes	Yes	Yes

Note: *, **, and *** indicate significant levels at 10%, 5%, and 1%, respectively

The partial derivatives with regard to the k^{th} independent variable are as follows from area 1 to area N:

$$\left[\frac{\partial Y}{\partial X_{1k}}\cdots\frac{\partial Y}{\partial X_{nk}}\right]=\begin{bmatrix}\frac{\partial Y_1}{\partial X_{1k}} & \cdots & \frac{\partial Y_1}{\partial X_{nk}}\\ \vdots & \ddots & \vdots\\ \frac{\partial Y_n}{\partial X_{1k}} & \cdots & \frac{\partial Y_n}{\partial X_{nk}}\end{bmatrix}=(I-\rho W_{ij})^{-1}\begin{bmatrix}\beta_k & w_{12}\theta_k & \cdots & w_{12}\theta_k\\ w_{21}\theta_k & \beta_k & \cdots & w_{2N}\theta_k\\ \vdots & \vdots & \ddots & \vdots\\ w_{N1}\theta_k & w_{N2}\theta_k & \cdots & \beta_k\end{bmatrix} \tag{31}$$

where w_{ij} is the element (i,j) of the matrix W_{ij}. The direct effect is the average of the sum of the diagonal elements of the matrix (32). The indirect effect is the average of the sum of all row and column elements of the non-diagonal elements, which is also the spillover effect. The spatial panel models are estimated by maximum likelihood estimation (MLE) to avoid biased estimators. When LM-err is significant, the criterion for deciding the optimal spatial model is SEM, and when LM-lag is significant, SAR. The robustness of LM-err and LM-lag are compared if they are both substantial. The results are shown in the Tables 14 to 16 in Appendix D, indicating that SDM is the model with the best explanatory power. The aggregation of the transportation, warehousing, and postal sectors is significantly reduced as a consequence of the HSR's opening, as can be seen in Table 6, and they have a significant spillover impact on neighboring cities. Because HSR boosts urban housing costs, relatively low-end transportation and warehousing in the tertiary sector will be shifted to distant locations, with nearby cities being suitable places to accept them, leading to an increase in the industrial aggregation of these industries. This phenomenon is called the siphon

Table 6 Effect decomposition of different industries along Beijing-Guangzhou and Beijing-Shanghai lines

Variables	SEM	SAR			SDM		
	Direct	Direct	Indirect	Total	Direct	Indirect	Total
LQ_2	−0.1519***	−0.1473***	−0.0115	−0.1587***	**−0.0184*****	**0.0703**	**−0.1141**
	(−3.8694)	(−3.8387)	(−1.2294)	(−3.7030)	**(−3.9172)**	**(0.7359)**	**(−1.4300)**
LQ_4	−0.1187***	−0.0861***	−0.0305***	−0.1167***	**0.1771*****	**0.0292*****	**0.1150***
	(−4.7052)	(−3.7432)	(−2.8607)	(−3.5925)	**(−6.7065)**	**(4.3179)**	**(1.8330)**
LQ_7	−0.1134***	−0.1035***	−0.0159**	−0.0119***	**−0.1448*****	**0.1377*****	**−0.0071**
	(−6.4077)	(−6.1867)	(−2.2107)	(−5.6810)	**(−7.2599)**	**(3.2819)**	**(−0.2058)**
LQ_8	−0.0368	−0.0378	−0.0021	−0.0398	**0.0426**	**−0.2154**	**−0.1728**
	(−0.6570)	(−0.6762)	(−0.3953)	(−0.6791)	**(0.6282)**	**(−1.6232)**	**(−1.5984)**
LQ_10	−0.0885***	−0.0684***	−0.0407***	−0.1091***	**−0.0982*****	**0.1247***	**0.0265**
	(−3.6840)	(−3.0821)	(−2.6752)	(−2.9964)	**(−3.9350)**	**(1.8093)**	**(0.4055)**
LQ_11	0.1157***	0.1056***	0.0271***	0.1328***	**0.1344*****	**−0.0296**	**0.1048**
	(3.8898)	(3.7482)	(2.7698)	(3.7653)	**(4.0432)**	**(−0.3969)**	**(1.5386)**
LQ_13	−0.0146	−0.0145	−0.0013	−0.0159	**−0.0119**	**0.0122**	**0.0002**
	(−0.7204)	(−0.7200)	(−0.6322)	(−0.7318)	**(−0.4943)**	**(0.2581)**	**(0.0196)**
LQ_16	−0.0199	−0.0105	−0.0084	−0.0190	**−0.0317**	**0.0093**	**−0.0223**
	(−1.0490)	(−0.6076)	(0.6041)	(0.6017)	**(−1.6394)**	**(0.1534)**	**(−0.3620)**
LQ_17	−0.0465**	−0.0276	−0.0253	−0.0530	**−0.0601*****	**0.1428****	**0.0827**
	(−2.5483)	(−1.6468)	(−1.5662)	(−1.6128)	**(−1.6383)**	**(0.1509)**	**(−0.3600)**
LQ_19	−0.0104	−0.0018	−0.0016	−0.0035	**−0.0263**	**0.0267**	**0.0004**
	(−0.5588)	(−0.1174)	(−0.1239)	(−0.1113)	**(−1.3891)**	**(0.4233)**	**(0.0122)**

Bold indicates SDM is the model with the best explanatory power

Note: *, **, and *** indicate significant levels at 10%, 5%, and 1%, respectively

effect [2]. Furthermore, since the opening of HSR, there has been a structural shift in the tertiary industry, from basic to advanced sectors. By analyzing the heterogeneity of HSR in the industrial structure from the effects of HSR on the industry, HSR has an overall positive effect on most sectors, showing that the opening of HSR has fostered the aggregation of the tertiary industry as a whole. Debrezion (2007) [41], He (2020) [42], Huang (2020) [43], Shao (2017) [17], and Wang (2018) [44] studied the impact of HSR on real estate, automobiles, services, and finance, respectively, and found heterogeneity in the impact of HSR across industries, which is consistent with the findings in this paper.

5.4 Human Capital's Mediation Effect

Following the demonstration of the heterogeneity in the impact of *HSR* on various cities, it should be determined whether the impact is produced by the flow of human resources. In this paper, the number of college students is utilized as a variable to quantify human resources. If the coefficients of the three regressions are significant but c' is minor, then the human resource has an intermediary effect on the impact of *HSR* on industrial structure. Using the steps below:

$$Y = cX + e_1 \tag{32}$$

$$M = aX + e_2 \tag{33}$$

$$Y = c'X + bM + e_3 \tag{34}$$

where X is *HSR*, Y are dependent variables, and M is the mediator variable. The significance of *HSR*'s coefficients in Models (1), (3), and (5) in Table 7 demonstrates its explanatory power for Y and M. In Model (2), the partial intermediary effect of human resources is shown with a value of $ab/c = 0.0723$ for *LQ_third* as the explanatory variable. Because the *lwrdxs* coefficients in Model (4) are insignificant, the bootstrap test is required to obtain a distribution that is close to the population, and the results for SA are reported in Table 8. The sign of the coefficient in Table 8 is significantly positive, suggesting that human resources have only an indirect effect. Combining Tables 7 and 8, it can be concluded that human resources serve as a complete intermediary in the impact of *HSR* on the industrial structure.

Table 7 Intermediary effect test of human capital

Variables	(1) *LQ_third*	(2) *LQ_third*	(3) *SA*	(4) *SA*	(5) *lwrdxs*
lwrdxs		−0.028***		−0.005	
		(−2.96)		(−0.94)	
HSR	0.029***	0.026***	0.021***	0.019***	−0.067***
	(3.62)	(3.31)	(4.53)	(4.12)	(−2.63)
lgdp_average	−0.046***	−0.038***	0.038***	0.038***	0.320***
	(−5.12)	(−3.98)	(7.19)	(6.84)	(11.09)
lwage_average	0.029***	0.029***	0.000	0.001	0.011*
	(14.36)	(14.53)	(0.42)	(0.44)	(1.70)
lfdi	−0.013***	−0.012***	0.004**	0.004**	0.015
	(−4.31)	(−4.17)	(2.07)	(2.13)	(1.56)
lhuman_capital	0.035*	0.045**	−0.023*	−0.024*	0.332***
	(1.65)	(2.06)	(−1.84)	(−1.93)	(4.83)
fee	0.000	−0.000	0.000***	0.000***	−0.000***
	(0.37)	(−0.00)	(6.05)	(6.38)	(−4.24)
lroad_average	−0.022***	−0.013	0.019***	0.022***	0.325***
	(−2.79)	(−1.51)	(4.10)	(4.40)	(12.62)
ltele_pop	0.001	0.001	−0.002***	−0.002***	−0.012***
	(0.98)	(0.62)	(−3.46)	(−3.54)	(−3.92)
lbooks_average	0.034***	0.033***	−0.020***	−0.020***	−0.011
	(7.19)	(7.15)	(−7.46)	(−7.52)	(−0.71)
lhospital_num	0.015	0.013	−0.009*	−0.010*	−0.079***
	(1.59)	(1.34)	(−1.73)	(−1.88)	(−2.64)
Constant	0.538	0.420	2.172***	2.221***	−4.006***
	(1.47)	(1.12)	(10.12)	(10.22)	(−3.35)
City fixed	Yes	Yes	Yes	Yes	Yes
Time fixed	Yes	Yes	Yes	Yes	Yes
Observations	1,209	1,206	1,209	1,206	1,206
R-squared	0.861	0.861	0.911	0.912	0.951

Note: *, **, and *** indicate significant levels at 10%, 5%, and 1%, respectively

Table 8 Bootstrap test of SA

Variables	Coefficient	Bootstrap standard error	Z	P>|Z|	Normal-based [95% confidence interval]	
Indirect influence	0.010***	0.002	4.49	0.000	0.005	0.014
Direct influence	−0.002	0.006	−0.26	0.000	−0.014	0.011

Note: *, **, and *** indicate significant levels at 10%, 5%, and 1%, respectively

6 Discussion and Conclusion

With China's fast expansion of HSR, how to accurately quantify the impact of HSR on the industrial structure is of great concern to many scholars. In light of China's current state of the economy, the theoretical framework and hypothesis of the impact of HSR on the industrial structure are derived using the core–periphery model. This demonstrates that the impact of HSR on industrial structure aggregation includes decreasing-speed and U-shaped-speed aggregation, while the impact of HSR on industrial structure rationalization is uncertain. A series of empirical studies are based on the three hypotheses given in this paper.

The findings show that, first, HSR promotes tertiary industry aggregation and contributes to the transformation of the industrial structure from primary to the secondary and tertiary industry sector, as well as realizing the industrial structure advancement but not rationalization. Next, the impact of HSR on tertiary industry aggregation in major cities and high-density cities is greater than that in other cities, whereas the impact on the industrial structure advancement is smaller. Moreover, following the HSR's opening, the aggregation of the transportation, warehousing, and postal sectors has been greatly reduced, with a significant spillover effect on neighboring cities, proving the siphon effect and conduction mechanism of the HSR on industrial structure. There has also been a structural shift in the tertiary industry, from basic to advanced sectors. Finally, it has been confirmed that HSR decreases human resource flow costs and plays a partial intermediate function in the aggregation of tertiary industry, and the advanced industrial structure's intermediary role is clearer.

The primary contribution of this paper is the selection of appropriate research objects. The impacts of newly built stations and the rehabilitation of existing stations will overlap if all HSR in the area is evaluated, and the cross-effects will lead to skewed results. This study determines the suitable control and treatment groups for improving recognition accuracy after extensive comparison. The second contribution is that this research creates a mathematical economic geography model of the influence of HSR opening on the industrial structure based on Nobel laureate in Economics Krugman's core–periphery model. Samuelson's iceberg transportation cost notion is introduced, which is supplemented to provide a reference for follow-up research. The third contribution is that, unlike previous research, this work takes into account the heterogeneity of HSR's economic impacts across sectors, examines the direct and indirect heterogeneity of HSR on various industries in the city, and investigates the "siphon effect" of HSR.

As urbanization and the establishment of HSR progress, China should continue to boost investment in HSR development and make active use of resource allocation tools to aid in the transformation of the industrial structure. Simultaneously, it should not pursue tertiary industry growth blindly, in order to prevent the establishment of the siphon effect. The shortcomings of this paper, on the one hand, the data used are prefecture-level, not county-level units, potentially resulting in inadequate precision. This work, on the other hand, uses the whole railway line as the research object to prevent cross-influence, potentially resulting in a self-selection dilemma, which could be solved by segmenting the line to form a control group.

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Appendix

Appendix A: The Review of the Literature on High-Speed Rail and Economic Growth

See Table 9.

Table 9 A review of the literature on high-speed rail and economic growth

Literature	Research object	Hierarchy	Sample period	Identification method	Notes
Hall (2011)	UK	Nation	1976–2006	Statistics	–
Levinson (2012)	America	Nation	2012	Case analysis	–
Silva (2014)	Spain	Nation	1990–2010	SEM, MLE	–
AhlFeldt (2015)	Germany	Area	1995–2009	DID	Cologne–Frankfurt (HSR)
Pagliara (2017)	Italy	Nation	2006–2013	GLM	Impact on tourism
	China	Nation	2000–2014	FE	Colonial railway

Table 9 continued

Literature	Research object	Hierarchy	Sample period	Identification method	Notes
Haynes (2017)					
Guirao (2017)	Spain	Area	2004–2015	FE	Labor migration in Madrid
Juan (2018)	Spain	Area	2002–2014	OLS, FE	Labor migration in metropolises such as Madrid, Barcelona, and Malaga
Cascetta (2020)	Italy	Nation	2008–2018	Case analysis	Reduced reachability fairness by 11%
Shao (2017)	China	Yangtze River Delta region	1995–2014	Multi-period DID	Train frequency in the service industry
Dong (2018)	China	Nation	2003–2015	Multiphase DID, IV	China's 1961 railway line and minimum spanning tree as instrumental variables
Meng (2018)	China	Nation	2006–2014	Multi-period DID	Using the familiarity of county-level city data, a new mathematical model was constructed based on the model of Fujita (1999).
Zheng (2019)	China	98 cities	2004–2013	Multi-period DID	Calculation of spatial spillover effects of high-speed railway stations in China
Wang (2019)	China	Yangtze River Delta region	2000–2013	Gravity model	Research on the evolution law of hierarchical structure and physical structure
Wang (2019)	China	Yangtze River Delta region	2005–2016	Multi-period DID	Study population mobility and structure
Pan (2019)	China	Yangtze River Delta region	2008–2010 2012–2014	SARAR	Fine-grained nighttime light levels represent the level of economic growth
Liu (2020)	China	Yangtze River Delta region	1995–2015	Multi-period DID	A method to study the spatial integration of aggregations is proposed
Liang (2020)	China	Guangdong, Guangxi, Guizhou	2012–2017	PSM-DID	Using NPP-VIIRS remote sensing data to represent the regional economic growth
Li (2020)	China	40 prefecture-level cities	2001–2017	SCM	Using a synthetic control method
Wang (2020)	China	Nation	2004–2013	PSM-DID	Using DMSP/OLS and night lighting data
Li (2020)	China	61 prefecture-level cities	2008–2017	DID, threshold effect model	Research on the relationship between HSR frequency and economic efficiency
Meng (2021)	China	Nation	2008–2017	Multiphase DID, IV	Constructing the HSRON model to study the effect of NP on SIA

Appendix B: The list of HSR and cities along and outside the Beijing–Shanghai and Beijing–Guangzhou HSR

See Tables 10, 11.

Table 10 A list of the history of the opening of some high-speed rail

High-speed rail line	Mileage (km)	Speed (km/h)	Opening time
Beijing–Tianjin intercity railway	115	350	2008/08/01
Wuhan–Guangzhou passenger dedicated line	968	300	2009/12/26
Zhengxi passenger dedicated line	484	300	2010/02/06
Changjiu intercity railway	131	300	2010/09/20
Hainan east ring railway	308	250	2010/12/30
Changji intercity railway	111	250	2010/12/30
Beijing–Shanghai high-speed railway	1318	325	2011/06/30

Table 10 continued

High-speed rail line	Mileage (km)	Speed (km/h)	Opening time
Hebong passenger dedicated line	131	350	2012/10/16
Harbin-Dalian passenger line	904	300	2012/12/01
Shiwu passenger dedicated line	841	300	2012/12/26
Hangyong passenger dedicated line	150	300	2013/07/01
Nanjing-Hangzhou passenger dedicated line	249	300	2013/07/01
Panying passenger dedicated line	90	300	2013/07/01
Hengliu railway	498	250	2013/12/28
Liunan intercity railway	226	250	2013/12/28
Wuxian intercity railway	90	300	2013/12/28
Xibao passenger dedicated line	148	250	2013/12/28
Qinfang railway	63	250	2013/12/30
Yongbei line	199	250	2013/12/30
Nanguang railway	577	250	2014/04/18
Wuhuang intercity railway	133	250	2014/06/18
Daxi passenger dedicated line	859	250	2014/07/01
Hangzhou-Changzhou passenger dedicated line	924	300	2014/09/16
Changkun passenger dedicated line	706	300	2014/12/16
Chengmianle passenger dedicated line	319	250	2014/12/20
Guiguang passenger dedicated line	861	250	2014/12/26
Lanxin railway second double line	1787	250	2014/12/26
Qingrong intercity railway	299	250	2014/12/28
Hefu passenger dedicated line	808	300	2015/06/28
Haqi passenger dedicated line	286	250	2015/08/17
Shendan passenger line	208	250	2015/09/01
Jihun passenger dedicated line	378	250	2015/09/20
Jinbin intercity railway	45	350	2015/09/20
Lanzhong intercity railway	63	250	2015/09/30
Ning'an passenger dedicated line	257	250	2015/12/06
Nankun passenger dedicated line	710	250	2015/12/11
Chengdu-Chongqing passenger line	305	300	2015/12/26
Jinwen railway capacity expansion and reconstruction project	188	250	2015/12/26
Lanzhou-Chongqing railway	352	250	2015/12/26
Jinbao railway	145	250	2015/12/28
.			

Table 11 List of cities along and outside the Beijing–Shanghai and Beijing–Guangzhou high-speed rail

Cities along the line	Beijing–Shanghai high-speed rail:	
	Beijing (1)	Beijing
	Tianjin (1)	Tianjin
	Shanghai (1)	Shanghai
	Hebei (2)	Cangzhou, Langfang
	Jiangsu (6)	Nanjing, Wuxi, Suzhou, Zhenjiang, Xuzhou, Changzhou
	Anhui(3)	Suzhou, Chuzhou, Bengbu
	Shandong (5)	Jinan, Zaozhuang, Tai'an, Dezhou, Jining
	Beijing–Guangzhou high-speed railway:	
	Beijing (1)	Beijing

Table 11 continued

Hebei (4)	Shijiazhuang, Handan, Baoding, Xingtai	
Henan (8)	Zhengzhou, Zhumadian, Anyang, Xinxiang, Xinyang, Hebi, Xuchang, Luohe	
Hubei (3)	Wuhan, Xiaogan, Xianning	
Hunan (5)	Changsha, Zhuzhou, Hengyang, Yueyang, Chenzhou	
Guangdong (3)	Guangzhou, Shaoguan, Qingyuan	
Cities outside the line	Beijing–Shanghai high-speed rail:	
	Hebei (3)	Zhangjiakou, Chengde, Hengshui
	Jiangsu (7)	Nantong, Huai'an, Lianyungang, Taizhou, Suqian, Yancheng, Yangzhou
	Anhui(3)	Yicheng, Fuyang, Haozhou
	Shandong (7)	Linyi, Binzhou, Rizhao, Laiwu, Liaocheng, Heze, Dongying
	Beijing–Guangzhou high-speed railway:	
	Hebei (3)	Zhangjiakou, Chengde, Hengshui
	Henan (4)	Pingdingshan, Puyang, Nanyang, Zhoukou
	Hubei (6)	Shiyan, Xiangyang, Huangshi, Ezhou, Jingmen, Suizhou,
	Hunan (4)	Changde, Zhangjiajie, Yiyang, Yongzhou
	Guangdong (6)	Heyuan, Zhanjiang, Maoming, Meizhou, Jiangmen, Yangjiang

Appendix C: Tests in heteroscedasticity, multicollinearity, and RESET

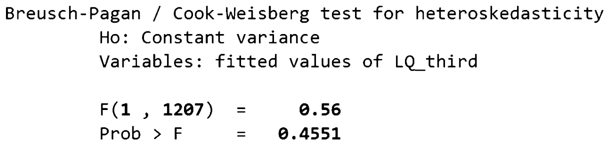
See Table 12.

Table 12 Variance inflation factors

Variables	VIF	1/VIF
lgdp_average	5.82	0.1720
road_average	3.45	0.2897
lbooks_average	2.77	0.3610
lfdi	2.54	0.3937
lhospital_num	2.39	0.4190
lhuman_capital	2.27	0.4405
fee	1.74	0.5759
ltele_pop	1.71	0.5802
hsr	1.37	0.7277
lwage_average	1.35	0.7407
Mean	2.54	

Heteroscedasticity Test

Considering the possible influence of heteroscedasticity, the BP test was performed on the heteroscedasticity of the data. The basic principle of the BP test is to test whether there is heteroscedasticity through auxiliary regression, as shown in Fig. 7. The results show that the null hypothesis is accepted, indicating that there is no obvious heteroscedasticity effect in the data set, and further discussion can be continued. The verified industry-advanced SH and industrial structure rationalization SR have also passed the BP test.



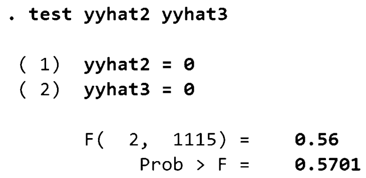
```
Breusch-Pagan / Cook-Weisberg test for heteroskedasticity
         Ho: Constant variance
         Variables: fitted values of LQ_third

         F(1 , 1207)  =     0.56
         Prob > F     =   0.4551
```

Fig. 7 The results of the BP test

Multicollinearity Test

The variance inflation factor is a measure of the severity of multicollinearity in a multiple linear regression model, and it represents the ratio of the variance of the regression coefficient estimator compared with the variance assuming non-linear correlations among the independent variables. A rule of thumb for judging whether there is multicollinearity is that the VIF of the independent variable should not exceed 10, otherwise multicollinearity may become a problem. B.1 shows that the VIF of all variables does not exceed 10, that is, there is no obvious multicollinearity for the variables in this paper.



```
. test yyhat2 yyhat3

 ( 1)  yyhat2 = 0
 ( 2)  yyhat3 = 0

       F(  2,  1115) =    0.56
            Prob > F =    0.5701
```

Fig. 8 Regression setting error test

RESET Test

Considering the effect of possible omitted interactions of higher-order terms and other variables, a regression set error test (RESET) was performed. It is a general method for testing functional form in multiple regression models. Its rationale is a joint significance F-test of squared, cubic, and possibly higher powers of the fitted values derived from the original OLS estimate. Fig. 8 Accepting the null hypothesis means that the model does not obviously miss the need to include complex interaction terms between all independent variables and higher-order terms of the respective variables, and the next in-depth analysis can be carried out.

Appendix D: Division standard of industries and test results of spatial correlation

See Tables 13, 14, 15, and 16.

Table 13 Division standard of three industries

LQ1	Primary industry	Agriculture, forestry, animal husbandry, and fishery
LQ2	Secondary industry	Mining industry
LQ3		Manufacturing
LQ4		Production and supply of electricity, gas, and water
LQ5		Construction industry
LQ6	Tertiary industry	Wholesale and retail trade
LQ7		Transportation, warehousing, and postal industry
LQ8		Accommodation and catering
LQ9		Information transmission, computer
LQ10		Financial industry
LQ11		Real estate
LQ12		Leasing and business services
LQ13		Scientific research and technical services
LQ14		Water conservancy, environment and public facilities management industry
LQ15		Residential services, repairs and other services
LQ16		Education industry
LQ17		Health, social security
LQ18		Culture, sports, and entertainment industries
LQ19		Public administration and social organization

Table 14 Test results of spatial correlation of LQ_third

	Spatial error: Moran's I	Spatial error: Lagrange multiplier	Spatial error: Robust Lagrange multiplier	Spatial lag: Lagrange multiplier	Spatial lag: Robust Lagrange multiplier
2003	2.424	2.604	3.318	0.004	0.719
	0.015	0.107	0.069	0.949	0.397
2004	2.908	4.515	3.914	0.652	0.051
	0.004	0.034	0.048	0.419	0.821
2005	2.916	4.583	4.671	0.263	0.351
	0.004	0.032	0.031	0.608	0.553
2006	2.722	3.929	0.207	0.207	0.339
	0.006	0.047	0.649	0.649	0.560
2007	1.397	0.571	1.121	0.139	0.690
	0.162	0.450	0.290	0.709	0.406
2008	1.875	1.490	1.840	0.005	0.354
	0.061	0.222	0.175	0.946	0.552
2009	5.010	15.688	13.507	2.354	0.173
	0.000	0.000	0.000	0.125	0.678
2010	3.373	6.862	4.873	2.023	0.034
	0.001	0.009	0.027	0.155	0.853
2011	3.717	8.065	4.989	3.453	0.376
	0.000	0.005	0.026	0.063	0.540
2012	3.176	5.432	2.876	3.581	1.025
	0.001	0.020	0.090	0.058	0.311
2013	3.078	5.158	2.784	3.466	1.093
	0.002	0.023	0.095	0.063	0.296
2014	1.335	0.508	0.041	1.975	1.508
	0.182	0.476	0.840	0.160	0.219
2015	1.078	0.245	0.190	0.060	0.005
	0.281	0.620	0.663	0.806	0.945
2016	0.295	0.067	0.067	0.002	0.001
	0.768	0.795	0.795	0.968	0.969
2017	0.276	0.058	0.049	0.009	0.000
	0.783	0.809	0.824	0.923	0.983

Table 15 Test results of spatial correlation of LQ2–LQ10

	LQ_2	LQ_3	LQ_4	LQ_5	LQ_6	LQ_7	LQ_8	LQ_9	LQ_10
2003	1.673	0.877	5.814	1.298	3.443	2.453	1.779	0.731	1.203
	0.094	0.620	0.000	0.194	0.001	0.014	0.075	0.465	0.229
2004	2.296	0.324	6.472	0.617	1.564	1.147	0.684	0.955	2.104
	0.022	0.254	0.000	0.537	0.118	0.251	0.494	0.339	0.035
2005	2.304	0.235	3.895	1.149	0.812	0.812	0.958	1.578	1.414
	0.021	0.186	0.000	0.251	0.417	0.417	0.338	0.115	0.157
2006	2.090	0.223	4.608	1.766	0.953	1.591	3.420	1.456	2.304
	0.037	0.176	0.000	0.077	0.340	0.111	0.001	0.146	0.021
2007	1.837	0.562	2.740	2.777	1.095	1.025	3.405	0.877	2.762
	0.066	0.574	0.006	0.005	0.274	0.305	0.001	0.380	0.006
2008	3.946	1.400	3.314	1.241	1.173	1.101	3.405	0.931	2.658
	0.000	0.162	0.001	0.215	0.241	0.271	0.001	0.352	0.008

Table 15 continued

	LQ_2	LQ_3	LQ_4	LQ_5	LQ_6	LQ_7	LQ_8	LQ_9	LQ_10
2009	3.178	0.596	3.134	0.426	1.241	0.588	4.575	1.609	2.416
	0.001	0.449	0.002	0.670	0.215	0.557	0.000	0.108	0.016
2010	4.175	0.235	4.405	1.450	1.442	0.306	2.214	0.638	2.047
	0.000	0.186	0.000	0.147	0.149	0.240	0.027	0.523	0.041
2011	3.687	0.827	4.135	0.743	0.895	0.542	0.714	0.684	1.483
	0.000	0.592	0.000	0.457	0.371	0.412	0.475	0.494	0.138
2012	3.885	0.984	2.695	−0.099	1.401	0.594	1.475	0.896	2.007
	0.000	0.325	0.007	1.079	0.161	0.448	0.140	0.370	0.045
2013	2.779	0.660	2.177	2.390	1.834	0.672	1.936	0.681	2.159
	0.005	0.509	0.029	0.017	0.067	0.501	0.053	0.504	0.031
2014	2.281	0.230	2.988	2.441	1.040	0.326	4.533	0.503	2.402
	0.023	0.818	0.003	0.015	0.298	0.745	0.000	0.615	0.016
2015	1.607	1.040	3.391	2.842	1.903	0.490	3.481	1.000	2.288
	0.108	0.298	0.001	0.004	0.057	0.376	0.000	0.317	0.022
2016	1.923	1.261	4.473	3.335	2.221	0.279	3.346	0.534	1.997
	0.054	0.207	0.000	0.001	0.026	0.780	0.001	0.593	0.046
2017	1.935	1.309	3.982	4.331	1.537	1.196	0.751	0.941	1.037
	0.053	0.191	0.000	0.000	0.124	0.232	0.453	0.347	0.300

Table 16 Test results of spatial correlation of LQ11–LQ19

	LQ_11	LQ_12	LQ_13	LQ_14	LQ_15	LQ_16	LQ_17	LQ_18	LQ_19
2003	0.001	0.001	1.614	5.205	0.818	2.098	4.191	0.212	2.029
	0.999	0.999	0.107	0.000	0.413	0.036	0.000	0.168	0.042
2004	0.509	0.300	3.128	3.568	1.339	2.238	4.058	0.529	1.514
	0.611	0.764	0.002	0.000	0.181	0.025	0.000	0.597	0.130
2005	0.188	1.186	3.064	2.278	1.518	1.382	2.692	1.187	0.588
	0.851	0.764	0.002	0.023	0.129	0.167	0.007	0.235	0.557
2006	1.050	0.582	4.056	2.640	1.557	2.186	2.179	1.591	1.632
	0.294	0.439	0.000	0.008	0.119	0.029	0.029	0.112	0.103
2007	1.828	0.747	4.073	1.936	2.083	2.450	0.965	1.847	1.865
	0.068	0.545	0.000	0.053	0.037	0.014	0.334	0.065	0.062
2008	1.316	0.262	3.003	1.415	1.606	0.170	0.563	1.783	1.140
	0.188	0.207	0.003	0.157	0.108	0.865	0.573	0.075	0.254
2009	1.151	0.208	2.842	2.384	1.115	1.568	0.291	1.925	0.996
	0.250	0.165	0.004	0.017	0.265	0.117	0.771	0.054	0.319
2010	1.070	0.524	2.033	0.370	1.700	0.541	0.149	1.223	1.294
	0.285	0.399	0.042	0.712	0.089	0.588	0.118	0.221	0.196
2011	1.869	0.181	3.039	0.816	0.973	2.861	1.645	0.222	1.249
	0.062	0.856	0.002	0.414	0.331	0.004	0.100	0.176	0.212
2012	0.078	0.171	4.988	1.538	1.752	1.734	0.921	0.374	1.223
	0.938	0.864	0.000	0.124	0.080	0.083	0.357	0.708	0.221
2013	1.550	1.870	5.417	0.405	1.053	1.556	2.338	1.786	2.482
	0.121	0.939	0.000	0.315	0.293	0.120	0.019	0.074	0.013
2014	2.888	1.614	5.835	0.345	0.006	1.312	3.114	2.216	2.529
	0.004	0.893	0.000	0.270	0.995	0.189	0.002	0.027	0.011
2015	2.858	1.387	5.831	0.862	1.597	0.692	2.412	3.207	2.996
	0.004	0.834	0.000	0.611	0.110	0.489	0.016	0.001	0.003

Table 16 continued

	LQ_11	LQ_12	LQ_13	LQ_14	LQ_15	LQ_16	LQ_17	LQ_18	LQ_19
2016	3.100	0.360	5.678	0.858	1.573	1.186	2.767	3.827	3.355
	0.002	0.719	0.000	0.609	0.116	0.236	0.006	0.000	0.001
2017	3.178	0.714	3.899	1.004	2.310	1.992	3.306	4.529	3.439
	0.001	0.475	0.000	0.315	0.021	0.046	0.001	0.000	0.001

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Data Availability The data were collected from the China Statistical Yearbook and the China City Statistical Yearbook.

References

1. Spiekermann K, Wegener M (1994) The shrinking continent: new time–space maps of Europe. Environ Plann B Plann Des 21(6):653–673. https://doi.org/10.1068/b210653
2. Niu F, Xin Z, Sun D (2021) Urban land use effects of high-speed railway network in China: a spatial spillover perspective. Land Use Policy 105. https://doi.org/10.1016/j.landusepol.2021.105417
3. Donaldson D (2010) Railroads of the raj: estimating the impact of transportation infrastructure. Lse Res Online Doc Econ 32(2):16487. https://doi.org/10.1257/aer.20101199
4. Alexander K (2015) Improving transport infrastructure in Russia. OECD Econ Dep Work Pap 1193:1–22. https://doi.org/10.1787/5js4hmcs3mxp-en
5. Fageda X, Gonzalez-Aregall M (2017) Do all transport modes impact on industrial employment? Empirical evidence from the Spanish regions. Transp Policy 55:70–78. https://doi.org/10.1016/j.tranpol.2016.12.008
6. Chandra A, Thompson E (2000) Does public infrastructure affect economic activity? Evidence from the rural interstate highway system. Reg Sci Urban Econ 30(4):457–490. https://doi.org/10.1016/S0166-0462(00)00040-5
7. Holl A (2004) Transport infrastructure, agglomeration economies, and firm birth: empirical evidence from Portugal. J Reg Sci 44(4):693–712. https://doi.org/10.1111/j.0022-4146.2004.00354.x
8. Aschauer DA (1989) Is public expenditure productive? J Monet Econ 23(2):177–200. https://doi.org/10.1016/0304-3932(89)90047-0
9. Chen CL, Hall P (2011) The impacts of high-speed trains on British economic geography: a study of the UK's intercity 125/225 and its effects. J Transp Geogr 19(4):689–704. https://doi.org/10.1016/j.jtrangeo.2010.08.010
10. Levinson DM (2012) Accessibility impacts of high-speed rail. J Transp Geogr 22:288–291. https://doi.org/10.1016/j.jtrangeo.2012.01.029
11. Chen G, Silva J (2014) Estimating the provincial economic impacts of high-speed rail in Spain: an application of structural equation modeling. Soc Behav Sci 111:157–165. https://doi.org/10.1016/j.sbspro.2014.01.048
12. Ahlfeldt GM, Feddersen A (2017) From periphery to core: measuring agglomeration effects using high-speed rail. Serc Discuss Pap. https://doi.org/10.1093/jeg/lbx005
13. Chen Z, Haynes KE (2017) Impact of high-speed rail on regional economic disparity in China. J Transp Geogr 65:80–91. https://doi.org/10.1016/j.jtrangeo.2017.08.003
14. Guirao B, Lara-Galera A, Campa JL (2017) High speed rail commuting impacts on labour migration: the case of the concentration of metropolis in the Madrid functional area. Land Use Policy Int J Cover All Aspects Land Use 66:131–140. https://doi.org/10.1016/j.landusepol.2017.04.035
15. Guirao B, Campa JL, Casado-Sanz N (2018) Labour mobility between cities and metropolitan integration: the role of high-speed rail commuting in Spain. Cities 78:140–154. https://doi.org/10.1016/j.cities.2018.02.008
16. Cascetta E, Cartenì A, Ih A, Henke I (2020) Economic growth, transport accessibility and regional equity impacts of high-speed railways in Italy: ten years ex post evaluation and future perspectives. Transp Res Part A: Policy Pract 139:412–428. https://doi.org/10.1016/j.tra.2020.07.008
17. Shao S, Tian Z, Yang L (2017) High speed rail and urban service industry agglomeration: evidence from China's Yangtze River Delta region. J Transp Geogr 64:174–183. https://doi.org/10.1016/j.jtrangeo.2017.08.019
18. Dong X (2018) High-speed railway and urban sectoral employment in China. Transp Res Part A Policy Pract 116:603–621. https://doi.org/10.1016/j.tra.2018.07.010
19. Meng X, Lin S, Zhu X (2018) The resource redistribution effect of high-speed rail stations on the economic growth of neighbouring regions: evidence from China. Transp Policy 68:178–191. https://doi.org/10.1016/j.tranpol.2018.05.006
20. Wang F, Wei X, Liu J, He L, Gao M (2019) Impact of high-speed rail on population mobility and urbanisation: a case study on Yangtze river delta urban agglomeration, China. Transp Res Part A Policy Pract 127(SEP.):99–114. https://doi.org/10.1016/j.tra.2019.06.018
21. Zheng L, Long F, Chang Z, Ye J (2019) Ghost town or city of hope? the spatial spillover effects of high-speed railway stations in China. Transp Pol 81(SEP.):230–241. https://doi.org/10.1016/j.tranpol.2019.07.005
22. Pan H, Cong C, Zhang X (2020) How do high-speed rail projects affect the agglomeration in cities and regions? Transp Res Part D: Transp Environ 88:102561. https://doi.org/10.1016/j.trd.2020.102561
23. Wang S, Wang J, Liu X (2019) How do urban spatial structures evolution in the high-speed rail era? Case study of Yangtze River Delta, China. Habitat Int 93:102051. https://doi.org/10.1016/j.habitatint.2019.102051
24. Liu Y, Zhang X, Pan X, Ma X, Tang M (2020) The spatial integration and coordinated industrial development of urban agglomerations in the Yangtze River economic belt China. Cities 104. https://doi.org/10.1016/j.cities.2020.102801

25. Liang Y, Zhou K, Li X, Zhou Z, Sun W, Zeng J (2020) Effectiveness of high-speed railway on regional economic growth for less developed areas. J Transp Geogr. https://doi.org/10.1016/j.jtrangeo.2019.102621
26. Li X, Wu Z, Zhao X (2020) Economic effect and its disparity of high-speed rail in China: a study of mechanism based on synthesis control method. Transp Policy 99:262–274. https://doi.org/10.1016/j.tranpol.2020.09.003
27. Li Y, Chen Z, Wang P (2020) Impact of high-speed rail on urban economic efficiency in China. Transp Policy 97:220–231. https://doi.org/10.1016/j.tranpol.2020.08.001
28. Wang C, Meng W, Hou X (2020) The impact of high-speed rails on urban economy: an investigation using night lighting data of Chinese cities. Res Transp Econ. https://doi.org/10.1016/j.retrec.2020.100819
29. Meng TA, Tl A, Xy B, Hz A, Xia MA (2021) The impact of high-speed rail on service industry agglomeration in peripheral cities. Transp Res Part D: Transp Environ. https://doi.org/10.1016/j.trd.2021.102745
30. Melo PC, Graham DJ, Brage-Ardao R (2013) The productivity of transport infrastructure investment: a meta-analysis of empirical evidence. Reg Sci Urban Econ 43(5):695–706. https://doi.org/10.1016/j.regsciurbeco.2013.05.002
31. Hansen WG (1959) How accessibility shapes land-use. J Am Inst Plann 25(1):73–76
32. Guy M, Ferdinand R, Redding SJ (2008) Urbanization and structural transformation. Quart J Econ 2:535–586. https://doi.org/10.1016/10.2139/ssrn.1281691
33. Pagliara F, Mauriello F, Garofalo A (2017) Exploring the interdependences between high-speed rail systems and tourism: some evidence from Italy. Transp Res Part A: Policy Pract 106:300–308. https://doi.org/10.1016/j.tra.2017.09.022
34. Duflo E, Pande R (2007) Dams. Q J Econ 122(2):601–646. https://doi.org/10.1162/qjec.122.2.601
35. Durarnton G, Turner MA (2011) The fundamental law of road congestion: evidence from US cities. Am Econ Rev 101(6):2616–2652. https://doi.org/10.1257/aer.101.6.2616
36. Turner G (2012) Urban growth and transportation. Cepr Discuss Pap 79(4):1407–1440. https://doi.org/10.2307/23355076
37. Melitz MJ (2003) The impact of trade on intra-industry reallocations and aggregate industry productivity. Econometrica 71(6):1695–1725. https://doi.org/10.1111/1468-0262.00467/
38. Richard EB et al (2006) Heterogeneous firms, agglomeration and economic geography: spatial selection and sorting. J Econ Geogr 6(3):323–346. https://doi.org/10.1093/jeg/lbi020
39. Melitz MJ, Ottaviano G (2008) Market size, trade, and productivity. Rev Econ Stud 75(1):295–316. https://doi.org/10.1111/j.1467-937x.2007.00463.x
40. Pace RK, Lesage JP (2009) A sampling approach to estimate the log determinant used in spatial likelihood problems. J Geogr Syst 11(3):209–225. https://doi.org/10.1007/s10109-009-0087-7
41. Debrezion G, Pels E, Rietveld P (2007) The impact of railway stations on residential and commercial property value: a meta-analysis. J Real Estate Financ Econ 35(2):161–180. https://doi.org/10.1007/s11146-007-9032-z
42. He SY (2020) Regional impact of rail network accessibility on residential property price: modelling spatial heterogeneous capitalisation effects in Hong Kong. Transp Res Part A Policy Pract. https://doi.org/10.1016/j.tra.2020.01.025
43. Huang Z, Du X (2020) How does high-speed rail affect land value? Evidence from China. Land Use Policy 101. https://doi.org/10.1016/j.landusepol.2020.105068
44. Wang L, Yuan F, Duan X (2018) How high-speed rail service development influenced commercial land market dynamics: a case study of Jiangsu Province, China. J Transp Geogr 72:248–257. https://doi.org/10.1016/j.jtrangeo.2018.09.010