High-Speed Railway station Impact on Regional Economic Development in China: An Empirical Analysis Using the SDID Model

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[Abstract]

This research delves into the profound implications of high-speed railway station construction on regional economic development in China. Employing the SDID model, the study meticulously analyzes the opening of high-speed railway stations and its subsequent impact on county-level economies. The findings, drawing from empirical data, underscore the following pivotal conclusions: Firstly, the study establishes a positive correlation between the introduction of high-speed railway stations and economic growth at the county level. Beyond the direct impact, the research illuminates the existence of spatial spillover effects, affirming the transformative influence of high-speed railway station construction on county economies. Secondly, the investigation reveals that high-speed railway station openings play a crucial role in the upgrading of industrial structures within counties. This effect is particularly pronounced in central and western regions, emphasizing the broader implications for economic activity concentration and growth in both primary and tertiary industries. Thirdly, the study highlights the nuanced nature of the impact of high-speed rail construction, contingent on regional characteristics such as existing infrastructure, population density, and industry structure. Policymakers are urged to consider these local nuances for effective planning and implementation.

In light of these conclusions, the research posits several key policy recommendations. Firstly, a thorough evaluation of the economic impact on neighboring counties is recommended before planning and constructing high-speed rail networks to mitigate potential negative spatial spillover effects. Secondly, policymakers are encouraged to adopt spatially differentiated policies, considering both direct and spatial spillover effects. Tailored approaches, accounting for regional disparities in economic development, can maximize the positive impacts of high-speed rail infrastructure. Thirdly, recognizing the spatial agglomeration effects of high-speed rail stations, the study recommends strategic placement in central locations to enhance economic networks, fostering inter-regional trade and facilitating the flow of people, goods, and capital. Lastly, the study underscores the importance of prioritizing accessibility and connectivity. High-speed rail, by reducing commuting costs, attracts residents to areas with lower living costs and high environmental quality. Policymakers should ensure selected station sites are easily accessible and connected to local transportation modes, with a focus on counties with significant economic development potential.

In conclusion, this research contributes valuable insights into the multifaceted impact of high-speed railway infrastructure on China's economic development. By considering regional nuances and implementing targeted policies, high-speed railway has the potential to serve as a catalyst for sustainable economic growth, industrial advancement, and spatial integration across the nation. Future research could delve into heterogeneous effects on economic growth and explore broader impacts on the environment, society, and culture.

[Key Words]

Spatial spillover externality; Spatial heterogeneity; Industry heterogeneity

1. Introduction

The rapid development of China's economy has been greatly supported by the construction and acceleration of the high-speed railway network. In the past decade, China's high-speed rail construction has undergone significant improvements and progress. The national high-speed rail passenger traffic has increased at an average annual growth rate of 23.38% from 2012 to 2020, with an average increase of 21.37% in passenger turnover. China's high-speed rail planning has been upgraded from the "four vertical and four horizontal" plan in 2008 to the "eight vertical and eight horizontal" road network construction plan. By 2013, 317 districts and counties across the country had opened high-speed rail stations. This figure increased to 510 in 2019. As of December 2021, China's high-speed rail operating mileage exceeded 40,000 kilometers, ranking first in the world. China's total railway operating mileage exceeded 150,000 kilometers, ranking second in the world. It is of great practical significance to study the influence of high-speed rail on the regional economic development of China.

As the most fundamental administrative and economic unit in China, the county economy is a fusion zone of rural and urban economies. The opening of high-speed rail station in county-level provides a more efficient and convenient way of commuting between rural areas, counties, and cities. Since 2008, China's high-speed railway construction has included a large number of counties into the coverage of the railway network, and the energy radiation of the development of the central urban area has gradually shifted to the county space, the county area has become an important node for network development. The network structure of high-speed rail in county-level has become an important spatial model that needs to be explored.

This paper conducts empirical research based on the natural experiment of HSR station opening at the county-level in China from 2013 to 2019 to explore the neighbor effect and regional heterogeneity caused by the HSR station to the county economy, with the aims to test the following two correlations: first, whether the high-speed rail stations opening will bring economic growth and spillover at the spatial level of the county economy; second, whether it will help the development of a more balanced spatial structure of the national county economy, and whether it will promote the further agglomeration of the macro-regional economy in space; third to explore whether the HSR will improve the industry structure to utilize the high-quality economy. Building upon the existing literature, this study employs the Spatial Difference-in-Differences (SDID) model to investigate the spatial neighbor effects, regional heterogeneity effects, and industry heterogeneity effects of high-speed rail opening on county-level economies wishing to provides a powerful tool for isolating the causal impact of high-speed rail development while controlling for potential confounding factors, thereby enhancing the robustness and validity of the empirical findings.

The remainder of this paper is structured as follows: the second part provides a literature review, followed by the third part, which presents the theoretical hypothesis. The fourth part discusses the data sources and variable design, and the fifth part introduces the model construction. The sixth part discusses the impact of high-speed rail access on the spillover of county economic space, the impact of high-speed rail spillover on regional disparity, and the influence of high-speed rail on the high-quality development of regional economy through tertiary industry

development. The seventh part concludes the article.

2. Literature review

Three main aspects have been identified by scholars regarding HSR's impact on the regional economy. The first aspect is the economic growth effect, which takes roles in accelerating transportation and communication efficiency and reducing commuting and transportation costs to improve regional economic growth. Aschauer (1989), Rohr and Williams (1994), Goodwin and Pearman (1994), Bruyelle and Thomas (1994), Zhang Nannan and Xu Yilun (2015), Kim Kwang Sik (2000), Sun Feiyang and Mansury Yuri S (2016), Ahlfeldt Gabriel M, Feddersen Arne (2010), Vickerman Roger (2015), and Zhang Xueliang (2012), have demonstrated the positive impact of HSR on economic growth, and three dimensions have been involved, namely, the investment effect, cost-saving effect, and market access effect. The second aspect is the industrial structure effect of HSR, which transforms the industrial structure from primary to advanced industries in less developed areas. This facilitates the introduction of advanced production technology and human capital from developed areas to developing areas to enhance local county-economic efficiency, as demonstrated by Li Yuwei and Ni Pengfei (2013) and Qin (2017). The third aspect is the spatial structure effect, as explored by Ding Qiuxian, Zhu Lixia, and Zhang Hui (2015), Wang Li, Cao Youhui, and Qiu Fangdao (2017), Yu Tao, Chen Zhao, and Zhu Pengyu (2012), Calderón and Servén (2004), Dong Yanmei and Zhu Yingming (2016), and Wang Yufei and Ni Pengfei (2016), the impact of transportation infrastructure on the differentiation of regional economic development through spatial clustering and diffusion effects. The existing body of research, including studies by Calderón and Servén (2004), Dong Yanmei and Zhu Yingming (2016), and Wang Yufei and Ni Pengfei (2016), has demonstrated that transportation infrastructure affects the differentiation of regional economic development through the spatial agglomeration and diffusion effects proposed by the new economic geography school. This has resulted in heterogeneous development of spatial economies, as documented by scholars such as Clark et al. (1969) and Keeble et al. (1982). But as to whether this heterogeneity is more beneficial to developed or backward areas takes divergent views in the academic community. Vickerman (1995), Rodríguez-Pose and Fratesi (2004), and Rietveld (1989), have found through research on Europe's inter-regional transportation network that transportation infrastructure tends to favor core areas over economically backward peripheral areas. Thus, it may not be advisable to rely solely on transportation infrastructure, such as high-speed rail networks, to reduce the regional economic gap between developed and backward areas.The infrastructural endowment, which is referred to as the “social fixed capital”, is an important strength to improve economic growth (Aschauer,1989; Munell,1990; Hulten and Schwab,1995)." High-speed rail (HSR), as a modern and significant transportation infrastructure, has received considerable attention from researchers in terms of its role in regional economic development (Elhorst and Oosterhaven, 2008; Tierney, 2012; Chen, 2012; Duranton and Turner, 2012; Ahlfeldt and Feddersen, 2015).These studies have focused on the relationship between HSR and economic growth, but have relatively paid less attention to regional economic disparities, such as why certain areas are more developed than others and how HSR affects regional economic integration, division, and agglomeration growth. Such

disparities arise from the differential flow of population and factors in different regions. This, in turn, leads to different spatial economic development outcomes in the area (Li et al., 2014). Therefore, exploring the impact of HSR on regional disparities is an essential approach to guide policy-making for local governments.
Several studies suggest that the construction of HSR has a powerful economic agglomeration effect (Hall, 2009; Urena et al., 2009; Qin, 2017; Shao, 2017; Jetpan Wetwitoo and Hironori Kato, 2017). Prior research (Calderón and Servén, 2004; Dong Yanmei and Zhu Yingming, 2016; Wang Yufei and Ni Pengfei, 2016) has indicated that transportation infrastructure affects the differential differentiation of regional economic development through the action of two economic forces, namely spatial agglomeration (Krugman, 1985) and spatial diffusion effect (Baum-Snow, 2007), leading to the heterogeneous development of the spatial economy (Clark et al., 1969; Keeble et al., 1982).

However, the academic community holds different views on whether this heterogeneity is more beneficial to developed regions or backward regions. Some scholars (Vickerman, 1995; Rodríguez-Pose and Fratesi, 2004; Rietveld, 1989) have found that transportation infrastructure, such as Europe's trans-regional transportation network, is more conducive to the economic growth of the core region than the marginal and backward regions.Therefore, reducing the regional economic gap between developed and backward regions through transportation infrastructure may not be advisable, and exploring the impact of HSR on regional disparities is an essential approach to guide policy-making for local governments, represented by HSR networks. Using the Kuznet curve, Chen and Haynes (2017) analyzed the influence of the Chinese HSR system on regional economic disparities, while Qin (2017) investigated the distributional impact of high-speed rail upgrades in China using the general equilibrium effect and shows the importance of access in HSR. Ahlfeldt and Feddersen (2018) measure agglomeration effects using HSR, while Faber (2014) suggests that improved transport linkages can benefit core regions at the expense of peripheral regions through a trade channel.

In terms of research tools, previous studies have primarily used the double differential DID model, mainly focusing on city-level research samples (Wang and Meng, 2014). However, when conducting the DID analysis, they did not examine the externalities caused by spatial spillover effects at high-speed rail sites. Ding et al. (n.d.) studied the threshold effect of infrastructure space spillover but did not consider the regional economic heterogeneity caused by the opening of high-speed rail stations.

Afterall, these studies both important on the relationship between the HSR and economy growth, but less on regional economic disparity, such as why certain areas are more developed than others? Or how the HSR affects the regional economic integration, regional division, regional agglomeration growth, these are both caused by the different flow of population and factors in different regions, and then caused different final spatial economy development in the area (Li et al., 2014). So, to query how the HSR effects on the regional disparity is another important way to give the local government some policy guide.

3. Theoretical hypothesis

The phenomenon of space spillover in the county economy refers to the externalities caused by

the spatial proximity effects from adjacent counties and the agglomeration effect from peripheral areas towards central areas. High-speed rail (HSR) is considered to be a critical factor in promoting regional economic development and plays a significant role in achieving the development of the county economy. Based on prior research, this study employs a spatial double difference model (SDID) to investigate the temporal effect of HSR on the county economy, and to examine the spatial effect of HSR on neighboring areas and the regional spatial structure effect of HSR on the county economy. Specifically, this study aims to determine whether the opening of HSR stations at the county level in China breaks or maintains the spatial structure imbalance. In other words, does the opening of HSR stations at the county level promote further agglomeration or diffusion of China's spatial structure? To answer this question, we used county-level data from 2013-2019 in China to investigate the causal effects of HSR on the structure of economic space at the county-level and to determine whether the opening of HSR stations caused regional spatial externalities. The aim is to demonstrate the unbalanced effect of HSR access on the spatial structure of the county economy. Based on the foregoing, we propose the following theoretical hypotheses:

3.1 The Spatial Spillover Effect of HSR Access on the County Economy

In addition to serving as a factor in infrastructure construction, HSR also promotes economic growth through spatial externalities, that is, the opening of HSR and HSR stations has spatial economic effects. The rapid development of HSR provides a good sample for studying HSR as transportation infrastructure. Chinese scholars, including Liu Bingyun and Zhang Xueliang, have investigated the spatial spillover effect of transportation infrastructure on total factor productivity growth, as well as the spatial spillover effect of foreign transportation infrastructure on local economic growth. Their research proved that the spatial spillover effect is greater than the direct effect on local economic growth. Foreign scholars Nakamura and Ueda (1989) compared the population growth rates of external areas and shinkansen urban areas and found that the shinkansen has a significant spatial agglomeration and siphon effects on the population of external areas. Moreover, the establishment of HSR stations has a positive impact on the rural economy due to local natural tourism resources.

Therefore, the opening of HSR stations can lead to the formation of denser, more developed, and efficient traffic networks between county economy, in addition to the direct investment effect that drives economic growth, also has a spatial externality effect on the economy of neighboring counties. Based on this, we propose the following hypothesis:

Hypothesis 1: HSR access can promote spatial spillover externalities at the county level.

3.2The spatial structure effect of HSR access on the county economy

The phenomenon of unbalanced economic growth, as the essential characteristic and objective expression of regional economy, is often reflected through regional selectivity rather than comprehensiveness of economic growth. The county economy, as a diversified space, also shows the characteristics of unbalanced growth in different regions, with a difference between developed areas and backward areas, and universal growth of county economy is not observed. The theory of new economic geography suggests that the spatial gathering of economic

activities improves the spatial efficiency of agglomeration areas and endogenously promotes regional economic growth.

The presence of high-speed rail (HSR) stations, as noted by Kingsley E.H. (1997), represents a change in the spatial interaction patterns of regional connections and regional industrial complexes. The work of Gimpel (1993) further highlights the important role of HSR networks in changing socioeconomic structures and regional spatial patterns. Additionally, Thompson (1994) notes that HSR offers greater opportunity and competitiveness for peripheral areas that are far from the outlying conditions in which the core area is at a disadvantage. Therefore, the opening of HSR stations can lead to the formation of denser, more developed, and efficient traffic networks between central cities and marginal areas, resulting in changes to the regional and urban spatial structure due to the spillover effect and agglomeration effect. As such, this study proposes the following hypothesis:

Hypothesis 2: Access to HSR can promote the spatial agglomeration from backward areas towards developed areas.

3.3The industrial structure effect of HSR access on the county economy

According to the theory of equilibrium development proposed by Rosenstein-Rodan (1943), infrastructure development should meet local industrial specialization needs. Several studies have shown that the construction of high-speed rail has a significant positive impact on regional economic growth in eastern and large high-speed rail cities through employment, including secondary and tertiary industries, with a negative impact observed in other regions, consistent with Puga's findings. This suggests that the construction of high-speed rail may reduce the consumption level of cities with lower service or consumption levels, benefiting large cities and to some extent, harming small cities.

Moreover, the construction of high-speed rail has a positive effect on the economic growth of high-speed rail cities in the west by affecting the employment of the primary industry. Studies by Arduin (1995) and Bonnafous (1995) found that new high-speed rail stations in France have boosted the local economy and greatly encouraged the development of commerce, tourism, and other services. Additionally, Gibb et al. (1990) studied the impact of the Channel Tunnel on the surrounding area of the UK, focusing on the impact on ports and tourism in Devon and Cornwall. Therefore, this study proposes the following hypothesis:

Hypothesis 3: The HSR stations has a positive effect on the upgrading of the county's economic and industrial structure, particularly in terms of the upgrading of the secondary industry to the tertiary industry.

4.Data sources and Model building

4.1 Data sources

The empirical study in this paper mainly uses the high-speed rail opening and economic development data at the district and county level in China from 2013 to 2019, This paper retains 14,252 observations from 2,036 districts and counties as analysis samples after removing the

samples of districts and counties with incomplete data.

District and county high-speed rail opening data is mainly based on the "high-speed rail network" high-speed rail opening public information statistics, as of 2019, this paper counted a total of 14252 districts and counties that opened high-speed rail stations nationwide. Districts and counties across the country are considered as quasi-natural laboratories, and control groups and uncontrol groups are set up based on the opening or non-opening of high-speed rail stations. Dummy variables are used to represent districts and counties that have opened high-speed rail stations (represented by '1') and those that have not (represented by '0')."District and county GDP as the dependent variable, primary industry GDP" ARG", secondary industry GDP "IND", district and county area "SIZE", primary industry and secondary industry output value proportion "INS", economic density as the control variable, the national districts and counties are divided into East China, North China, South China, Southeast China, Southwest, Northwest and Northeast seven regional plates, the spatial spillover effect of high-speed rail stations is introduced into the general SDID model, that is, the spatial double difference model. The spatial spillover effect and spatial heterogeneity of the county economy brought about by the opening of high-speed rail stations were analyzing, and the spatial heterogeneity was based on the east-west and north-south differences of the county economy, and the impact of industrial upgrading and high-quality development brought about by them.

4.2 Model building

The Spatial DID (Spatial Differences-in-Differences, SDID) model is set on the basis of the traditional dual difference model, which fully considers the avoidance requirements of spatial multicollinearity. Classical SDID models include: Double Differential Spatial Error Model (SEMDID), Double Differential Spatial Autoregressive Model (SARDID), Double Differential Space Doberman Model (SDMDID), etc. The biggest feature of the spatial econometric model is that it relaxes the assumption that the spatial units are independent of each other, that is, there is a correlation between the local area and the neighboring area, and the changes in the local area variables not only directly affect the local area, but also affect the neighboring area, and finally act on the local area by affecting the neighboring area. The impact of the region on the region is called the Direct Effect, and the average impact of the region on the neighboring area is called the Indirect Effect or Spatial Spillover Effect.

The Spatial Lag of X Model (SLX) is the most combined with DID in the spatial econometric model, and SLX introduces (all) the spatial lag term of the independent variables at the right end of the equation of the ordinary linear model, in the form of equation (1)

$$Y = \alpha_1 N + X\beta + WX\theta + \epsilon \quad (1)$$

WX in equation (1) is the spatial lag term for all independent variables, and since the right end of the equation does not include the spatial lag term of the explanatory variable, the model can be treated as an ordinary linear model and estimated using the ols method. Thus, the β in equation (1) measures the magnitude of the direct effect, and θ measures the magnitude of the indirect effect (Vega & Elhorst, 2015). SDID is based on equation (1), but only the spatial lag term of the DID interaction term on the right side of the equation, and the rest of the independent

variables are used as control variables in their initial form, like equation (2):

$$Y = \alpha_1 N + X\beta + \varphi did + \theta W did + \epsilon \quad (2)$$

Among them, φ represents the direct effect of policy, that is, the treatment effect to be examined in most papers, while θ represents the indirect effect or spatial spillover effect of policy. According to the above standard DID model, the spatial DID model for the establishment of high-speed rail stations to the economic growth of counties across the country is as follows:

$$lnY_{it} = \alpha + \theta did_{it} + \beta_1 lnARG_{it} + \beta_2 lnIND_{it} + \beta_3 lnSIZE_{it} + \beta_4 INS_{it} + u_i + v_t + \mu_{it} \quad (3)$$

where Y_{it} is the variable being explained, high-speed rail station D_{it} is the explanatory variable, and the control variables are primary industry ARG_{it}, secondary industry IND_{it}, county area $SIZE_{it}$, and the output value ratio INS_{it} of the primary industry and the secondary industry.

Moreover, taking spatial factor into model (3), the generally spatial econometrics model as follow:

$$lnY_{it} = \rho W lnY_{it} + \alpha + \theta did_{it} + \beta_1 lnARG_{it} + \beta_2 lnIND_{it} + \beta_3 lnSIZE_{it} + \beta_4 INS_{it} + \theta' W \times did_{it} + \beta_1' W \times lnARG_{it} + \beta_2' W \times lnIND_{it} + \beta_3' W \times lnSIZE_{it} + \beta_4' W \times INS_{it} + u_i + v_t + \mu_{it} \quad (4)$$

With $\mu_{it} = \lambda W \mu_{it} + \varepsilon_{it}$

Where the coefficient of θ is the treatment effect, and θ' is the spatial term of did used to capture the spill-over effect of high-speed rail. Especially, if $\rho \neq 0, \lambda \neq 0$ and $W \times X_{it}$ in the model this is the SAC-DID. If $\rho = 0, \lambda \neq 0$ it is SEM-DID ;if $\rho \neq 0, \lambda = 0$, it is the SDM-DID, without taking spatial term into the model it become the SAR-DID.

W is the spatial weight matrix, with the value of 1, if the distance between two district($distance_{ij}$) is larger than 20km, and value of 0, with the distance smaller than 20km.

$$W_{it} = \begin{cases} 1, & distance_{ij} > 20km \\ 0, & distance_{ij} < 20km \end{cases} \quad (5)$$

4.3Variable Description

The purpose of this paper is to investigate the disparity of economic growth, industrial structure and spatial economic growth between the districts and counties with and without high-speed rail opening in the seven major regions of the country(according to the spatial distribution of China's regional economy, it is divided into Central China, South China, North China, East China, Southwest, Northwest and Northeast) from 2013 to 2019, thus demonstrating the impact of high-speed rail opening on high-quality economic development and spatial economic agglomeration. In the summary, the descriptive statistics of the main variable involved in this paper are report in Table 1

Table1 Descriptive statistics of main variables

Variables	Variable representation	N	MIN	MAX	MEAN	SD
station	HSR station open	14,252	0	1	0.122	0.327
d1	East China	14,252	0	1	0.212	0.409
d2	South China	14,252	0	1	0.156	0.363
d3	Central China	14,252	0	1	0.0742	0.262
d4	North China	14,252	0	1	0.146	0.353
d5	Southwest	14,252	0	1	0.162	0.368
d6	Northwest	14,252	0	1	0.0845	0.278
d7	Northeast	14,252	0	1	0.166	0.372
lnarg	The logarithm of primary industry gdp	14,252	7.518	14.28	12.05	1.035
lnind	The ogarithm of secondary industry gdp	14,252	4.419	16.85	12.95	1.390
ins	Proportion of primary industry to secondary industry	14,252	0.0678	119.1	1.285	1.881
r3	Proportion of tertiary industry to gdp	14,252	0.0607	0.910	0.392	0.112
lnsize	The logarithm ofcounty area	14,252	4.043	12.22	7.732	0.949
lngdp	The logarithm of gdp	14,252	9.674	17.52	13.91	1.142

5.Empirical test results

5.1 The Spatial Growth Effect of High-Speed Railway on County-level Economy

According to hypothesis 1: HSR access can promote spatial spillover externalities at the county level. We use the Double Difference Fixed Effects Model to estimate the spatial growth effect of High-Speed Rail on the County-level Economy, consider the spatial correlation between the independent variable spatial lags and the dependent variable, the results are as follows in Table 2:

Table2. the Double Difference Fixed Effects Model of HSR to County-level Economy growth

	SAC		SDM		SEM		SAR	
	Estimate	Se	Estimate	Se	Estimate	Se	Estimate	Se
lambda	0.44251082*	0.241511	-2.1791***	0.619951			-2.17484***	0.638415
rho	-5.7747471**	2.767679			-4.32753005***	1.302323		
station	0.01025551**	0.004148	0.009996*	0.004143	0.01017689**	0.004148	0.014484***	0.004277
lnarg	0.17489446***	0.002133	0.174842***	0.002132	0.17495354***	0.002133	0.174491***	0.002183
lnind	0.44470575***	0.003624	0.443896***	0.003627	0.44462875***	0.003625	0.425024***	0.003632
lnsize	-0.021378***	0.001521	-0.02145***	0.001519	-0.02140889***	0.001521	-0.02125***	0.001565
ins	0.05150236***	0.000867	0.051421***	0.000866	0.05149775***	0.000867	0.053259***	0.000893
wstation	-3.5492109***	0.342681	-3.52878***	0.342274	-3.5431169***	0.34269		
wlnarg	1.22387027***	0.121562	1.218013***	0.121428	1.22221546***	0.121568		
wlnind	0.54634857***	0.059642	0.545242***	0.059578	0.54606068***	0.059645		
wlnsize	0.57548471**	0.181951	0.573506**	0.181743	0.57505111**	0.181959		

wins	-0.0321	0.020527	-0.03185	0.020507	-0.03201	0.020529		

*, **, *** denote significance at the 10%, 5%, and 1% levels, respectively, for Pr(>|t|).

From the four models SAC, SDM, SEM, and SAR DID estimate result list in table 1, two roles can be seen from HSR regarding the County-level economy:

First, the spatial economic growth effect can be seen in table 2.

According to the data in the table, it can be seen that the influence of high-speed railway stations on county-level economies is significant in the SDM, SEM, and SAR models, and the impact is also close to significant in the SAC model. In the SDM, SEM, and SAR models, the coefficient of the impact of high-speed railway stations on county-level economies is 0.009996, 0.01017689, and 0.014484, respectively, all of which are positive, indicating a positive correlation between high-speed railway stations and county-level economies. This means that setting up more stations within a county will promote its economic development. The SAC model shows a slightly larger positive impact coefficient of 0.01025551 for high-speed railway stations compared to other models. This suggests that in the SAC model, the influence of high-speed railway stations on county-level economies is more significant and the spatial correlation within the economic system is strong and significant. Therefore, the opening of high-speed railway stations has a direct promotional effect on the economic growth at the county level.

As to the industry structure, the positive significant effect can be seen from HSR station to the primary industry and second industry. According to the data in the table, there is a positive correlation between the high-speed railway station and agricultural economy (lnarg) in all four models, and the regression coefficients are significant in all models (the Pr(>|t|) values are all less than 0.01). This indicates that the opening of a high-speed railway station can promote the development of the agricultural economy. One possible explanation is that the development of the county town brings more market demand and economic vitality, which stimulates the development of the surrounding agricultural economy. In addition, the construction of modern facilities and service facilities in the county town can also improve the efficiency and quality of agricultural production, thereby driving the development of the agricultural economy. Regarding the secondary industry, according to the regression results table given, it can be seen that in the SAC, SDM, and SEM models, the high-speed railway station is positively correlated with the natural logarithm of the secondary industry, while this variable is not included in the SAR model. Specifically, in the SDM model, the coefficient of the high-speed railway station is 0.009996 (with a p-value of 0.0158), and in the SEM model, the coefficient is 0.010177 (with a p-value of 0.0141). This means that when controlling for other factors, an increase in the high-speed railway station is accompanied by an increase in the natural logarithm of the secondary industry. In other words, the construction of high-speed railway stations has a positive impact on the development of the secondary industry. From the given table, we can also see that the station (high-speed railway station) is positively correlated with the ratio of the primary and secondary industries (ins), indicating that the establishment of a high-speed railway station will lead to an increase in the proportion of the primary industry and a decrease in the proportion of

the secondary industry. Specifically, in the SAC, SDM, and SEM models, the coefficients of the station are 0.0515, 0.0514, and 0.0515 respectively, and the p-values in all models are less than 0.05, indicating that this result is statistically significant. Therefore, it can be seen that the opening of a high-speed railway station is more conducive to the development of the primary industry compared to the secondary industry.

Second, got the space externality effect from HSR to the County-level economy.

In the SDM and SEM models, the estimated coefficients of rho here are -4.3275 and -2.1748, respectively, both negative and significant, indicating that an increase in economic activity level in surrounding areas would lead to a decrease in economic activity level in the region. The significant impact of the high-speed railway station in this county has a negative spatial effect on the economy of neighboring counties, indicating that the high-speed railway station in this county has negative spatial spillover effects on the economy of neighboring counties. This suggests that high-speed railway stations have significant spatial agglomeration effects, significant spatial autoregression, and obvious spatial growth effects, with a significant positive effect on the neighboring county areas. But as to the industry structure, couldn't see the significant adjacent relation effect, both the primary industry second industry are got no significant effect from HSR to the labor-county-economy.

5.2 The dynamic effect of HSR on economic growth

In this paper, we use the panel data to estimates the effect of highway access on the regional economic growth, which is different with the traditional DID method that has two-period sample only. And especially, in our sample, there are some treat group that has affect by the HSR in the first year of 2013. Hence, we select the sample that HSR doesn't open in 2014 to estimates the dynamics effect of HRS. As a consequence, there are two year hasn't affect by HSR.

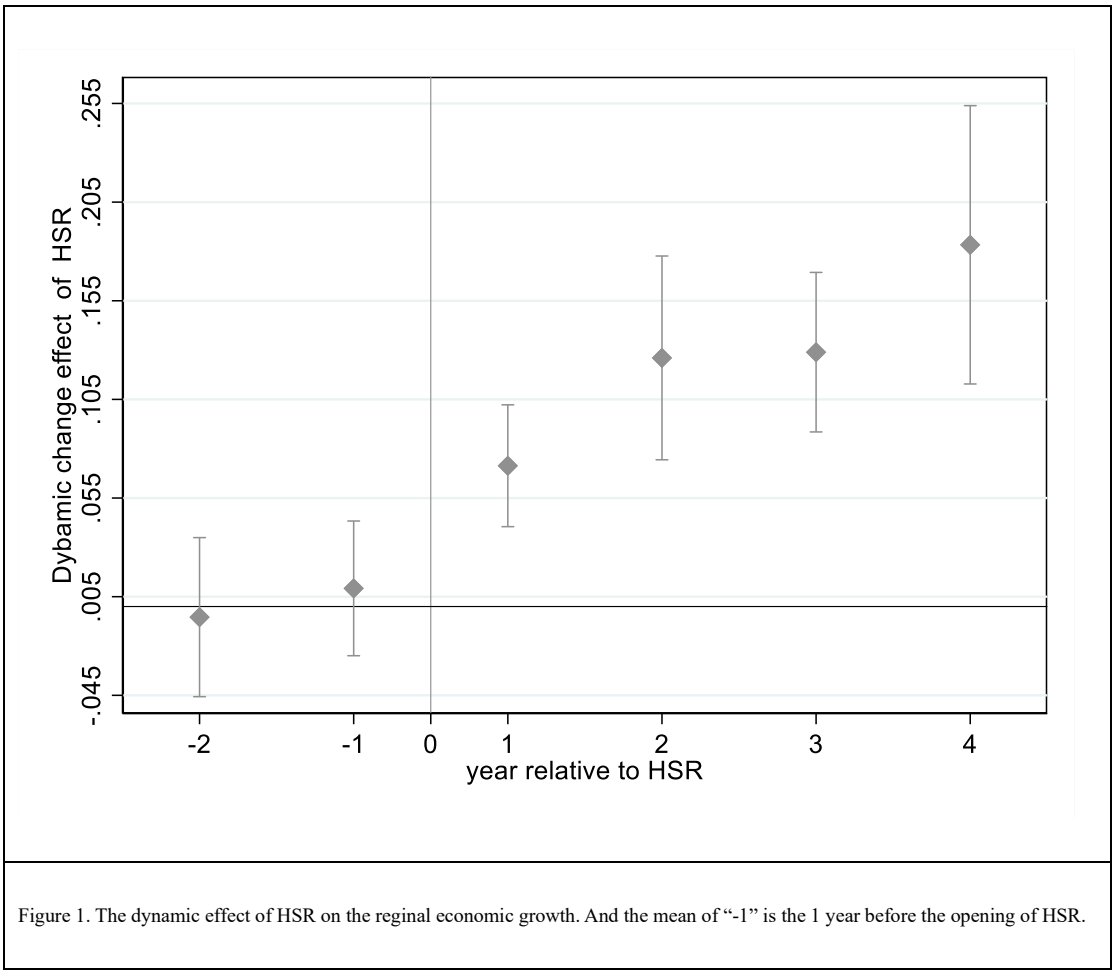

Figure 1. The dynamic effect of HSR on the reginal economic growth. And the mean of "-1" is the 1 year before the opening of HSR.

Figure 1 illustrates the dynamic effect of HSR on economic growth. As shown, the coefficients on HSR are insignificant different from zero for the two years before the opening of the highway speed rail, with no distinguish trend between control-groups and treat-groups before the opening of RHS. Then, note that the coefficients of RHS increase immediately from zero to positive value after the opening of RHS, and significant at 5% level. Moreover, the promote effect of RHS on economic growth has a high level at after 2-4 year after the opening of the HSR. In sum, figure 1 shows that we has passed the parallel trend test, the conclusion in this paper is robust.

5.3The spatial heterogeneity effect of HSR on county-level economy

As the concludes we gain above have been verify the hypothesis 1 that HSR access can promote spatial spillover externalities at the county level, now we'll continue to test hypothesis 2 that Access to HSR can promote the spatial agglomeration from backward areas towards developed areas. Also, we use the spatial Difference-in-Differences (DID) to analysis the impact of HSR opening on various districts and counties, where "station" is a dummy variable and "d1-d7" represent the dummy variables of Southwest, North China, Northeast, Northwest, East China, and Central China high-speed rail stations, respectively, with South China region (d6) as the base period. The econometric results are as follows in table 3:

Table 3. Regional Heterogeneity Using Dummy Variables (with South China as the Base Period)

	SAC		SEM		SDM		SAR	
	Estimate	Se	Estimate	Se	Estimate	Se	Estimate	Se
Station	0.0379***	0.0100	0.0375***	0.0100	0.0366***	0.0100	0.0354***	0.0103
*Station*d1*	-0.0730***	0.0135	-0.0725***	0.0135	-0.0713***	0.0135	-0.0565***	0.0139
*Station*d2*	0.0125	0.0157	0.0131	0.0157	0.0146	0.0157	0.0213	0.0162
*Station*d3*	-0.0491***	0.0184	-0.0489***	0.0184	-0.0484***	0.0184	-0.0442**	0.0191
*Station*d4*	-0.0200	0.0177	-0.0197	0.0177	-0.0188	0.0177	-0.0033	0.0183
*Station*d5*	0.0024	0.0119	0.0027	0.0119	0.0033	0.0119	0.0052	0.0123
*Station*d7*	-0.0773***	0.0134	-0.0770***	0.0134	-0.0761***	0.0134	-0.0749***	0.0138
lnarg	0.1753***	0.0021	0.1754***	0.0021	0.1753***	0.0021	0.1753***	0.0022
lnind	0.4432***	0.0036	0.4431***	0.0036	0.4424***	0.0036	0.4244***	0.0036
lnsize	-0.0211***	0.0015	-0.0211***	0.0015	-0.0211***	0.0015	-0.0211***	0.0016
ins	0.0513***	0.0009	0.0513***	0.0009	0.0512***	0.0009	0.0531**	0.0009
wstation	-3.7843***	0.3435	-3.7769***	0.3435	-3.7593***	0.3431		
wlnarg	1.2998***	0.1218	1.2978***	0.1218	1.2926***	0.1217		
wlnind	0.5795***	0.0597	0.5791***	0.0597	0.5778***	0.0596		
wlnsize	0.8089***	0.1856	0.8073***	0.1856	0.8024***	0.1854		

wins	-0.0406**	0.0205	-0.0405**	0.0205	-0.0402**	0.0205		
lambda	0.4536**	0.2304			-2.1814***	0.6163	-2.1743***	0.6350
rho	-5.9658**	2.7600	-4.4478***	1.3266				
Regional effect	yes	yes	yes	yes	yes	yes	yes	
Time effect	yes	yes	yes	yes	yes	yes	yes	
N	14252		14252		14252		14252	

*, **, *** denote significance at the 10%, 5%, and 1% levels, respectively, for Pr(>|t|).

As the data shows in table 3, the concludes can be gain as follows:

(1) The coefficient of the Station dummy variable indicates that the impact of HSR opening on the dependent variable is significantly positive (estimate is 0.0379, P-value is less than 0.001). This means that HSR access has a positive effect on the economic development and industrial structure changes of various districts and counties.

(2) The coefficients of the interaction terms between the dummy variables (d1-d7) of the HSR stations and the Station dummy variable show that the impact of HSR access on different districts and counties has regional differences. Among them, the interaction term coefficients of the Southwest region (d1) and the Northeast region (d3) are negative, indicating that the impact of HSR access on these two regions is less significant than that on other regions, while the interaction term coefficient of the East China region (d5) is positive, indicating that the impact of high-speed rail on this region is the most significant.

(3) The coefficients of other control variables (such as lnarg, lnind, lnsize, and ins) indicate that they have a significant positive or negative relationship with the dependent variable. For example, the coefficient of lnind (the natural logarithm of total industrial output value) is 0.4432, indicating a significant positive effect on the dependent variable.The presence of regional and time effects indicates that the model takes into account fixed effects of different regions and different times to eliminate their influence on the results.

(4) In summary, this analysis in table 3 provides preliminary results on the impact of HSR access on various districts and counties, showing that its impact has regional differences, and provides estimates of the impact of other control variables. To confirm the different impact of HSR access on different regions, we change the Base Period to East China, get the outcome as follows in table3.

Overall, the results suggest that there is significant regional heterogeneity in the data, and this needs to be taken into account when analyzing the data and making policy decisions. Analysising from table 3, the concludes can be gain as follows:

(1). The HSR access has a significant promoting effect on the economic growth of different regions and counties. The results in Table 3 show that the HSR can significantly promote county-level economic growth, and the effect of the HSR access varies among different regions.

(2). The HSR access has the most significant effect on the economic growth of counties in the South China region. it can be seen that compared to the base period of the East China region, the impact of the opening of high-speed railway stations on county-level economic growth in other regions are: the Southwest region has the largest negative impact, the North China region has no significant impact, the Northeast region has a negative impact, the Northwest region has a negative impact, the Central China region has no significant impact, and the South China region has the largest positive impact. This suggests that the effect of the HSR access on county-level economic growth varies significantly among different regions, and the South China region benefits the most.

Therefore, we can find that the HSR access has a significant promoting effect on county-level economic growth in different regions, but the impact varies significantly among different regions, mainly due to the influence of other control variables.

5.4 The industry structure heterogeneity

5.4.1the impact on second industry

When examining the impact of high-speed rail on the development of the second industry, it is essential to take into account the heterogeneity of industry structure. By utilizing the SAC, SEM, SDM, and SAR models, we are able to examine the causal relationship between the presence of high-speed railway stations and the development of the industrial sector. Based on the estimation results in Table 4, we can further explore the impact of high-speed rail on the second industry with a focus on second industry heterogeneity in the Couty-level in whole country.

Table 4. Estimated results of HSR Access on the development of the secondary industry.

	SAC		SEM		SDM		SAR	
	Estimate	Std.Error	Estimate	Std.Error	Estimate	Std.Error	Estimate	Std.Error
station	0.0115	0.0096	0.0115	0.0096	0.0113	0.0096	-0.0111	0.0099
lnarg	-0.1354***	0.0048	-0.1356***	0.0048	-0.1351***	0.0048	-0.1294***	0.0049

lnsize	-0.0717***	0.0035	-0.0717***	0.0035	-0.0716***	0.0035	-0.0845 ***	0.0035
ins	-0.1305***	0.0017	-0.1306***	0.0017	-0.1303***	0.0017	-0.1388 ***	0.0017
wstation	-5.2468***	0.5459	-5.2543***	0.5460	-5.2312***	0.5452		
wlnarg	2.3916***	0.2631	2.3943***	0.2632	2.3859***	0.2628		
wlnsize	7.1883***	0.3305	7.1893***	0.3304	7.1838***	0.3300		
lambda	-0.8833	3.4825			-3.1291***	1.0336	-3.3473 ***	1.0823
rho	-2.4408	6.2144	-3.6017***	1.1496				
Regional effect	yes		yes	yes	yes	yes	yes	
Time effect	yes		yes	yes	yes	yes	yes	
N	14252		14252		14252		14252	

(*, **, *** denote significance at the 10%, 5%, and 1% levels, respectively, for Pr(>|t|).)

The estimated results of the impact of the HSR access on the development of the secondary industry, as measured by four different regression models: spatial autoregressive model (SAC), spatial error model (SEM), spatial Durbin model (SDM), and spatial autoregressive model with a spatial lag dependent variable (SAR).The results show that the HSR has a positive but small effect on the development of the secondary industry, as indicated by the coefficient estimate of station (0.0115).

However, this effect is not statistically significant in any of the models. The coefficients for station, lnarg and lnsize are not significant, which indicates that the impact of HSR on the second industry is not homogeneous across regions or industries. Furthermore, the coefficients for wstation, wlnarg and wlnsize are significant, which suggests that the industrial structure heterogeneity affects the impact of HSR on the second industry. However, the estimates for lambda and rho are not significant, which implies that the regional and temporal effects do not play a significant role in the impact of HSR on the second industry. Overall, the results suggest that the impact of HSR on the development of the second industry depends on the heterogeneity of the industry structure.By the other side,the variables related to the size and investment of the

secondary industry have negative and statistically significant effects on its development, as indicated by the coefficient estimates of lnarg, lnsize.This suggests that the primary industry ,the county area have a harder time growing in the presence of high-speed rail.The spatial adjacent variable (wstation, wlnarg, wlnsize) have positive and statistically significant effects on the development of the secondary industry, suggesting that the industry tends to grow in areas where neighboring regions are also growing.

Finally, the spatial autoregressive coefficients (lambda and rho) have mixed results across the models, with only one model (SDM) showing a statistically significant negative effect of spatial dependence on the development of the secondary industry. This suggests that the development of the industry is not strongly influenced by the development of neighboring regions. In summary, the results suggest that the HSR access has a limited and insignificant impact on the development of the secondary industry, which is instead affected by the county-size and the growth of neighboring regions.

5.4.2the impact on Tertiary Industry

Table 5. Estimated Results of HSR access on the Development of the Tertiary Industry

	SAC		SEM		SDM		SAR	
	Estimate	Std.Error	Estimate	Std.Error	Estimate	Std.Error	Estimate	Std.Error
station	0.0447***	0.0091	0.0453***	0.0091	0.0446***	0.0091	0.0537***	0.0095
lnarg	0.1063 ***	0.0047	0.1064***	0.0047	0.1062***	0.0047	0.0994***	0.0049
lnind	0.1121***	0.0080	0.1131***	0.0080	0.1119 ***	0.0080	0.0649***	0.0081
lnsize	-0.0716 ***	0.0033	-0.0716***	0.0034	-0.0716***	0.0033	-0.0727***	0.0035
ins	0.0629 ***	0.0019	0.0632***	0.0019	0.0629 ***	0.0019	0.0670***	0.0020
wstation	-1.2442 *	0.7536	-1.2741*	0.7557	-1.2446 *	0.7534		
wlnarg	0.4148	0.2674	0.4237	0.2681	0.4149	0.2673		
wlnind	0.9335 ***	0.1312	0.9373***	0.1315	0.9334 ***	0.1311		

wlnsize	1.5570 ***	0.4002	1.5667***	0.4013	1.5571 ***	0.4001		
wins	0.2818***	0.0452	0.2822***	0.0453	0.2817***	0.0451		
lambda	-5.3757*	2.9360			-5.7290***	1.4708	-5.9060***	1.5416
rho	-0.2054	0.6620	-6.5348***	1.6947				
Regional effect	yes		yes	yes	yes	yes	yes	
Time effect	yes		yes	yes	yes	yes	yes	
N	14252		14252		14252		14252	

(*, **, *** denote significance at the 10%, 5%, and 1% levels, respectively, for Pr(>|t|).)

Table 5 presents the estimated results of the High-Speed Rail (HSR) access on the development of the tertiary industry, using four different regression models (SAC, SEM, SDM, and SAR) and various control variables,both regional and time effects are included in all four models,includes the estimated coefficients for the lambda and rho parameters, which represent the spatial autocorrelation effects. From the table results can be see that HSR access has a significant positive impact on the development of the tertiary industry, along with other control variables.

The lambda coefficient is negative and statistically significant in the SDM and SAR models, indicating the presence of spatial autocorrelation in the error term. The rho coefficient is negative and statistically significant only in the SDM model.From the four models SAC, SEM, SDM, and SAR, with estimates and standard errors for each model in table4, the variables related to HSR access, such as station, lnarg, lnind, lnsize, and ins, are found to be statistically significant at the 1% level. Specifically, for each model, the estimates for these variables are positive, indicating that HSR access has a positive impact on the development of the tertiary industry.In addition, the variables wstation, wlnarg, wlnind, and wlnsize are also included in the models, which represent the interaction effects between HSR access, which are negative but not statistically significant in the SAC, SEM, and SDM models.

Based on the results, several variables have significant impacts on the development of the tertiary industry: the results can be see that stations in the four models SAC, SEM, SDM, and SAR have positive impacts on the development of the tertiary industry, with estimates ranging from 0.0446 to 0.0537.lnarg (the logarithm of the primary industry), ins (industry structure proportion), and wins (neighboring county proportion industry structure) also have positive

impacts on the development of the tertiary industry, with estimates ranging from 0.0629 to 0.1063.lnind (the logarithm of the secondary industry), lnsize (the logarithm of the county size), wlnind (the interaction term between lnind and stations), and wlnsize (the interaction term between lnsize and stations) have negative impacts on the development of the tertiary industry, with estimates ranging from -0.0727 to 0.1121.The other interaction terms (wstation, wlnarg, wlnind, and wlnsize) are not significant.The lambda and rho parameters represent regional and time effects, respectively, and they have significant impacts on the development of the tertiary industry in some cases. Overall, the results suggest that HSR access can have a positive impact on the development of the tertiary industry, particularly in areas with high agriculture proportion. However, the impacts may vary depending on the industrial structure and city size of the regions.

6.Coclusion and Discussion

6.1 **Conclusion**

In conclusion, the construction of high-speed rail has a significant impact on regional economic development. Based on the empirical analysis of the data, we can draw the following conclusions:

(1)Firstly, this paper uses the SDID model to investigate the impact of high-speed rail station opening on county-level economic growth in China. The results show that the opening of high-speed rail stations has a positive impact on the economic growth of counties. At the same time, the impact of high-speed rail station opening on economic growth is not only direct but also indirect, indicating the existence of spatial spillover effects. the construction of high-speed rail has a significant positive effect on the economic growth of the county. The opening of high-speed railway stations has a direct promotion effect on the economic growth at the county level, which can be observed from the positive correlation between the high-speed railway station and county-level economy in all four models. This suggests that the construction of high-speed rail should be further promoted as it can enhance the economic development of regions that it serves.

(2)Secondly, The opening of high-speed rail stations promotes the upgrading of the industrial structure of the county, and the industrial structure upgrading effect is particularly significant in the central and western regions. In addition, the opening of high-speed rail stations also promotes the concentration of economic activities and regional economic growth.high-speed rail promotes the development of the primary and tertiary industries. The opening of high-speed railway stations has a significant positive effect on the agricultural economy, and a positive correlation between the high-speed railway station and the tertiary industry was observed in the SAC, SDM, and SEM models. This indicates that the construction of high-speed rail can promote the development of the primary and secondary industries.

(3)Finally, it is worth noting that the effects of high-speed rail construction may vary depending on the specific regional characteristics, such as the existing infrastructure, population density, and industry structure.Therefore, policymakers should consider local conditions when planning and implementing high-speed rail projects. In future research, more attention could be paid to the heterogeneity of high-speed rail station opening effects on economic growth in different regions and the impact on different types of industries. The government can adopt policies to

encourage the development of industries that are more compatible with high-speed rail infrastructure, such as the service industry, high-tech industry, and logistics industry. This will help to maximize the economic benefits of high-speed rail infrastructure and promote industrial structure upgrading in the regions that benefit from it. Moreover, the mechanism of how high-speed rail station opening promotes economic growth and its spatial spillover effects can be further explored. In addition, future research can focus on exploring the impact of high-speed rail on other aspects, such as the environment, society, and culture.

6.2 Discussion and policy recommendations

The results of the study suggest that the opening of high-speed rail stations has a significant positive impact on the economic development of districts and counties in China. Specifically, it promotes economic growth, industrial structure upgrading, and spatial economic agglomeration. These findings have important implications for policy makers in China and other countries considering the development of high-speed rail infrastructure. The policy recommendations can be suggested as follows:

(1) The study has important implications for policymakers in China, particularly in the context of the ongoing high-speed rail network construction. As the Hypothesis 1 prove that HSR access can promote spatial spillover externalities at the county level. The analysis suggests that the high-speed railway station in a county has negative spatial spillover effects on the economy of neighboring counties. Therefore, it is recommended to evaluate the economic impact of high-speed railway stations on neighboring counties before planning and constructing high-speed railway networks.

(2) The findings suggest that policymakers should pay attention not only to the direct impact of high-speed rail station opening on economic growth but also to its spatial spillover effects, and the policies should take into account regional differences in economic development. Efforts should be made to maximize the spillover effects of HSR infrastructure. Governments could incentivize the development of complementary industries and services around HSR stations to attract more businesses and visitors to the area.

(3) As to spatial heterogeneity, the government can use high-speed rail infrastructure to promote spatial economic agglomeration and regional integration. The HSR station both have significant spatial agglomeration effects and significant spatial autoregression. Therefore, the HSR station sites should choose the counties that in the local center to bring more economic networks. That's means the government should take into the spatial spillover effects when increase the HSR stations on the county level.The study found that high-speed rail stations have a significant spatial spillover effect, which means that the economic benefits of high-speed rail infrastructure can extend beyond the regions where the infrastructure is located. To fully capitalize on these benefits, the government can use high-speed rail infrastructure to connect different regions, promote inter-regional trade, and encourage the flow of people, goods, and capital between different regions.

(4) Encouraging prioritize accessibility and connectivity. The HSR effectively reduces commuting costs, at least in terms of the opportunity cost of travel time. According to

standard urban economics models, equivalence constraints mean that a reduction in commuting costs will attract new residents to these places where housing and living costs are relatively low and environmental quality is high. In turn, the increase in the resident population increases access to the local workforce and consumer markets, and may eventually attract new businesses. The selected station sites should be easily accessible and connected to other modes of transportation, such as local bus and metro systems, to ensure convenient travel for passengers. And the selection of HSR station sites should not only focus on economic benefits but also consider regional development. The selected station sites should help promote economic development in the surrounding areas, including job creation, industry clustering, and tourism development. So, the government should prioritize HSR development in counties that have the potential to benefit the most from the transportation infrastructure. This could include counties that are located near major metropolitan areas, have a high population density, and have strong economic growth potential. Also emphasizes should put on government to improve transportation connectivity within counties to maximize the benefits of HSR. This could include investments in local public transportation systems, bike lanes, and pedestrian walkways to connect HSR stations to key economic centers.

In conclusion, the study provides important insights into the economic impact of high-speed rail infrastructure in China. By promoting economic growth, industrial structure upgrading, spatial economic agglomeration, and sustainable development, high-speed rail infrastructure has the potential to play a critical role in the economic development of regions across the country.

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