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The Opening of High-Speed Railway and Coordinated Development of the Core–Periphery Urban Economy in China

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Abstract: The current study investigates the impact of the high-speed railway's operation on the coordinated economic development of "core–periphery" cities using the multi-period difference-in-difference (DID) model. Data on 270 prefecture-level cities in China were collected for empirical analysis of collected data. The findings demonstrate that the high-speed railway's operation has widened the economic development gap between core and peripheral cities and restrained the coordinated growth of the urban economy. The heterogeneity analysis found that the "siphon effect" of the high-speed railway's operation in core cities is only effective within the distance of "one-hour metropolitan area". Moreover, it is found that the high-speed railway has a threshold effect based on the size of cities. It depicts that the core cities in the high-speed railway network play a "siphon effect" and "diffusion effect" on large size cities and small (or medium) size cities, respectively, which is manifested as a suppression and promotion effect on the coordinated development of the urban economy. Furthermore, it is found that that technological innovation and economic agglomeration are two significant intermediary paths of high-speed railway opening that affect the level of "core–periphery" city economics coordination; however, technological innovation's role as an intermediary has a stronger masking effect than economic agglomeration.

Keywords: high-speed railway; core–periphery; urban economy; mediating effect; China

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1. Introduction

In the 40 years after reform and opening, China's economic development has been in a transitional phase. Beijing, Shanghai, and Guangzhou have developed as regional economic growth hubs because of the unbalanced envelopment strategy's emphasis on efficiency (Liu et al., 2022 [1]). However, at the same time, the unbalanced and uncoordinated development tendency among regional cities has gained prominence, which has also, in some ways, limited the release of the potential for regional economic growth. In recent years, the provincial core cities have continued to merge the peripheral cities' population, land, and other resources. The polarization of economic development among cities and the issue of big city diseases are becoming more prominent, which is counter to the strategic goal of balanced development of regional integration, even though the economic strength and "reputation" of the core cities are being further enhanced. Meanwhile, the strategic objective of balanced regional integration has been undermined by the polarization of urban economic development (Wang and Zhang, 2022 [2]). Improving the transportation infrastructure system is key to forming an effective geospatial organization of economic activities (Redding and Turner, 2015 [3]). Therefore, a significant number of scholars have demonstrated that the high-speed railway's operation can achieve the flow and reallocation of resources and elements by strengthening the economic links between cities, thereby affecting the coordination of regional economic development. However, the release path of the economic effect of this path is still debatable (Chen, 2022 [4]). Further research needs to be conducted on a number of problems, such as how the introduction of high-speed rail would affect the growth of inter-city connections and whether inter-city economic development is divided or integrated.

Existing research demonstrated that transportation infrastructure can alter the spatial economic growth pattern by exerting the economic distribution impact as a key medium for the free movement of production factors. For example, the accessibility of expressways can significantly improve the manufacturing efficiency, market power, and resource allocation efficiency of non-core cities (Li et al., 2019 [5]). The high-speed railway can also be a useful entrance point for integrating space resources and increasing urban functions due to its large passenger capacity, reduced time commitment, good safety, and high punctuality (Du et al., 2017 [6]). The regional urban system can, therefore, be improved by upgrading the transportation infrastructure (Wang and Yang, 2022 [7]). The operation of the high-speed railway, however, might minimize the space–time distance and speed up the process of creating a unified and sizable market, allowing non-core cities in the region to accept the economic benefits brought on by the relocation of enterprises as well as the spillovers of knowledge and technology from the core cities based on the "diffusion effect" of high-speed rails (Wang et al., 2021 [8]; Deng et al., 2019 [9]). However, it must also contend with the "siphon effect" of market competition, policy orientation, and other advantages of the core city on its internal factors, namely, the ease with which central cities can combine labor, capital, and other production factors from peripheral cities due to their advantage in labor costs and high rates of return on investment.

The opening of high-speed rail undoubtedly speeds up this process, which results in an increasing trend of uneven spatial and technological development (Deng, 2017 [10]). Some studies contend that because of the "aisle effect" brought on by the operation of high-speed rail, improvements to transportation infrastructure do not have a significant economic growth impact on most node cities in the region. Instead, it is found that the region's initial equilibrium state of resource allocation, which encourages resources to congregate in large cities and causes the economic development of the periphery to "stagnate" (Mi Diao, 2018 [11]; Feng and Cui, 2020 [12]; Xu et al., 2022 [13]). This pattern was also observed in research on the expansion of high-speed rail in other nations. According to the report, Tokyo and Osaka, the Shinkansen's node cities in Japan, have expanded their markets to include smaller towns. Cities near the center of high-speed rail lines benefit more than periphery cities due to external variables such as the heterogeneous distribution of elements. The development of high-speed rail in Manchester and Lille has also marginalized the peripheral regional economy. Therefore, it is not always adequate to drive the development of peripheral cities by improving the traffic accessibility between core and peripheral cities under the "core-periphery'–periphery" regional spatial layout model (Fujita and Mori, 1996 [14]). How the high-speed railway opening influence coordinated urban economic growth is still determined by the strength of the "diffusion effect" and "siphon effect" of the core city, affecting the economic development of peripheral cities. However, by summarizing the findings of the previous studies, it is found that most scholars focused on the critical factors affecting economic development, such as industrial structure (Li et al., 2016 [15]), urban population size (Deng et al., 2019 [9]), and refactoring (Guirao et al., 2018 [16]) of the high-speed rail node cities. Considering the introduction of high-speed rail from a spatial perspective, only a few scholars have focused on the effect of urban connectivity on regional economic cooperation.

The competition and interest coordination between core and peripheral cities have been more pronounced as the regional transportation infrastructure network construction becomes more and more precise. Two categories can be used to sum up the literature on the competitive dynamics between cities. Competition is one of the elements. According to the "core–periphery" theory of new economic geography, when a region has a relative resource endowment advantage, the region can produce a "agglomeration effect" on the production factors of other regions through the optimization mechanism of factors so that all types of production factors continue to flow into the core city (Bian, 2019 [17]).

The second element is the level of market competition. Due to the core city's advantages in terms of industrial resources and its position in the regional industrial chain (Zhong and Sun, 2015 [18]), the market radiation range of its businesses is extending more quickly to the neighboring peripheral cities (Sun et al., 2022 [19]). The "crowding out effect" on the uniform businesses of outer cities then develops. Peripheral cities' lower level of competitiveness causes their economies to stagnate and makes regional financial incompatibility worse. The "core–periphery" cities have a competitive relationship with one another, but there is also synergy and mutual benefit. The following are the key findings of the literature review that was already conducted: The center city has a mechanism in place to compensate the outlying cities throughout the later stages of economic development (Zhou, 2009 [20]). The "feedback effect" of the central city on the economic growth of the outlying cities can be formed by the return of components (Zhu et al., 2012 [21]). Unfortunately, the compensation is frequently invalidated by the passage of time in the value judgment of the compensation mechanism (Liu et al., 2022 [1]). As a result, the "siphon effect" is still in action in the central city. Although the stable industrial chain built on the basis of cooperation and specialized division of labor in industry can strengthen the bonds between cities, the process of agglomeration and decentralization of factors also aids in deepening these bonds, speeding up the realization of industrial synergy among cities at various levels (Wu and Shen, 2013 [22]). The literature mentioned above demonstrates the need for developing an appropriate mathematical model to assess the relationship between the economic development of cities and to further investigate the internal relationship between transportation infrastructure and the coordinated growth of the urban economy regarding "core–periphery" cities.

Therefore, in this study, we used 270 statistics at the prefecture level and above in mainland China from 2006 to 2019 and treated the opening of the high-speed railway as a "quasi-natural" experiment. A multi-period difference-in-differences model was used to empirically test the effect and specific path of the opening of the high-speed railway on urban economic coordination, which is characterized by the gap in economic development between core and non-core cities. The main research question of this study is: How does the high-speed rail operation effect the coordination of the economies of the cities within the province? For establishing rational resource allocation and improving the sustainable growth of regional economies, this research question is crucial. The two main contributions of this study are as follows: (1) The impact of high-speed rail operation on the integration of the economies of Chinese cities is investigated in this study. A heterogeneity test based on the "geographical distance effect" and the size of the city is also carried out. (2) Utilizing mediating variables, we assessed the variations in the new high-speed railway opening mechanism's mediating impact on urban economic coordination (economic agglomeration and technology innovation).

2. Theoretical Framework and Hypotheses

2.1. High-Speed Railway Opening and Coordinated Development of "Core- Periphery" Urban Economy

The expansion of the regional high-speed rail network successfully reduced the temporal and physical separation between towns, drew cities closer together, and created favorable conditions for further removing obstacles to factor flow at urban boundary lines. Aiming to increase the economic vitality of peripheral cities and to promote the coordinated development of the "core–periphery" urban economy, the core city also serves as the "growth pole" of the local economy and plays a significant leadership and radiation role that influences the economic development of peripheral cities via the "diffusion effect."

Krugman et al. (1991 [23]), on the other hand, discovered that under the new economic geography framework, the economy-of-scale effect of core cities could effectively reduce the trade costs of cities and improve the efficiency of production, resulting in the siphoning effect of factors of production such as labor and capital. The free movement of generation elements throughout space is further encouraged by advancements in transportation infrastructure. A high-speed railway's opening is based on the "time-space compression impact" created by its extensive transportation system, which creates the "reallocation effect" of factor resources by lowering the cost of factor flow and broadening the range of factor flows. Relatively free flow is predicated on the idea that elements frequently move to areas with better marginal returns. A single city dominance phenomenon is seen in the core city of the region as a result of the core city's ideal industrial structure and market structure, which has the advantages of a return on capital and labor compensation and draws in capital, labor, and other factors to further optimize the resource endowment conditions of the core city at the expense of the interests of the periphery cities.

When the "diffusion effect" of the core city in the region brought on by the opening of the high-speed railway is stronger than the "siphon effect," it illustrates the promotional influence on the coordinated growth of the "core–periphery" urban economy. Instead, it can create the "Matthew Effect", which illustrates the disequilibrium of local economic expansion. In light of this, we proposed the following research hypotheses.

Hypothesis 1a. *Opening high-speed rail lines may enhance the level of coordinated economic growth of the "core–periphery" urban economy.*

Hypothesis 1b. *Opening high-speed rail lines may prevent the coordinated growth of a "core–periphery" metropolitan economy.*

2.2. High-Speed Railway Opening, Economic Agglomeration, and Coordinated Development of "Core–Periphery" Urban Economy

As urban accessibility improves, the benefits of urban location and economic development become more salient, resulting in the change in urban agglomeration rent and the agglomeration or diffusion of urban space (Li et al., 2016) [15]. Due to the inverted U shape of agglomeration rent, different impacts of agglomeration or dispersion of cities along the high-speed railway may occur. From the point of view of "core–periphery" cities, the high-speed railway's operation can accelerate the transfer of manufacturing enterprises from core cities to the high-speed peripheral railway or non-high-speed railway cities with lower production costs. Some scholars have indicated that locating and building high-speed rail has affected the location of businesses. For example, the impact of the high-speed railway's operation on house prices and land prices have led manufacturing firms to migrate to less developed regions or cities (Zhu et al., 2022 [24]).

On the other hand, under the assumption that the city has the benefits of resource endowment and market potential, opening a high-speed railway will promote the agglomeration of tertiary industries such as producers and knowledge-intensive services in the city (Tang 2021 [25]; Tang and Gu 2018 [26]; Huo and Wei [27]). As a result, the high-speed railway's operation in core cities can enhance its "agglomeration effect" on tertiary industry firms, thereby promoting the urban industry's transformation towards a high-value direction. The "circular accumulation effect" formed by the modernization of industrial structures and the economic agglomeration of the high-speed railway will help to continually strengthen the scale and level of urban economic agglomeration and generate economy of scale, strengthening the core cities' economic resilience. Based on this theory, the given hypothesis is proposed.

Hypothesis 2. *Through economic agglomeration, the high-speed railway's operation indirectly affects the coordinated expansion of the "core–periphery" urban economy.*

2.3. High-Speed Railway Opening, Technological Innovation, and Coordinated Development of the "Core–Periphery" Urban Economy

Given that urban transportation infrastructure is a necessary component of technological innovation activities, optimizing high-speed rail networks is also essential for changing the spatial distribution of innovation. Talents serve as the intellectual foundation for urban technological growth and innovative activities. The opening of the high-speed railway has the potential to increase accessibility in urban areas and speed up talent flows by lowering worker commuting expenses, shortening commuting times, and increasing commuting frequency. It is coupled with the “introducing talents” and “introducing technology” in the city, thus, providing intellectual support for urban technological innovation. In addition, the construction of high-speed rail lines broadens opportunities for “face-to-face” exchanges of elite labor forces between cities engaged in technical R&D and other industries. Urban innovation is given the centrifugal force that propels the diffusion of economic activities and the flow of talent to peripheral cities, as well as propels the general improvement of regional levels of technology. These factors are accomplished by accelerating the spatial spillover of knowledge and technology, the process of externalizing tacit knowledge, as well as by reducing information asymmetry between cities and realizing deeper specialization and technological complementarities. According to Yang and Luo (2019 [28]), the development of high-speed rail has an impact on how human capital is allocated. This effect includes the “siphon effect” of technological innovation factors such as talent caused by the operation of high-speed rail in core cities, which is likely to cause the knowledge gap between cities and the “Matthew effect” of technological innovation, thereby inhibiting technological innovation. Being the primary force behind urban economic development, urban technological innovation capacity and level have an impact on the coordinated growth of the regional economy (Shi and Guo, 2020 [29]). Therefore, the high-speed railway’s opening may have an impact on the coordinated growth of the urban economy via the particular channel of technical advancement. Its course of action still needs to be confirmed, though. The given hypothesis is proposed to prove it empirically.

Hypothesis 3. *The impact of the high-speed railway’s operation on the coordinated growth of the “core–periphery” urban economy is intermediately influenced by technological advancement.*

3. Material and Methods

3.1. Model Construction

The difference-in-difference model, a popular econometric tool for assessing the impact of policies, was used, which may avoid endogenous issues. There is a “time effect” and a “policy treatment effect” since operating high-speed rail is a “quasi-natural” experiment. Whether high-speed rail is opened or not in each observation year, we constructed a multi-phase difference-in-difference (DID) model and divided sample cities into experimental and control groups.

$$lnGAP_{it} = \alpha_0 + \alpha_1 HSR_{it} + \alpha_2 Controls_{it} + \mu_{it} + \nu_{it} + \varepsilon_{it} \quad (1)$$

where GAP_{it} represents the level of coordinated regional development of city i in year t. The variable HSR_{it} is the dummy variable for whether city i opens a high-speed railway in year t. Controls represents the control variable. μ_i and ν_t are the fixed effects of city and year, respectively. ε_{it} is the random error term assumed to be normally distributed at zero mean value (Ahmed et al., 2016 [30]; Peng et al., 2020 [31]; Zhao et al., 2020; Zhao et al., 2021; Zhong et al., 2020 [32–34]) and constant variance (Altangerel et al., 2015 [35]; Elahi and Khalid, 2022 [36]; Elahi, Khalid, et al., 2022 [37]; Elahi et al., 2017 [38]; Elahi, Zhang, et al., 2022 [39]; Scaringella and Chanaron, 2016 [40]).

3.2. Descriptions of Variables

3.2.1. Explained Variables

The strategy utilized in this research for the “core–periphery” urban economic coordinated development level is motivated by Lan and Zhang’s work (2021 [41]). The “core–periphery” urban economic development gap at the province level is used to measure the extent of coordinated urban economic development. The single-core provinces and double-core provinces are determined using the weighted value of the average quantity of the city's per capita GDP and population size (the number of people working in the city at the end of the year), where the provincial capital weighted value comes in first. A province is considered to have a single core if its weighted value ranks first. A province is considered to have two cores if it has a prefecture-level city that is ranked higher than the provincial capital in terms of weighted value. Afterward, we calculated the difference in economic development between the central city and the outlying ones. It follows that the amount of coordinated growth of the urban economy will be higher, or lower, depending on how close the distance is between the province's main city and its outlying cities. Equation (2) provides the calculation's formula.

$$
\begin{gathered}
GAP_{pi} = \frac{PGDP_{cj}}{PGDP_{pi}} \\
GAP_{cj} = \frac{\sum_{i=1}^{n} GAP_{pi}}{n} \\
GAP_{pi} = \left(\frac{PGDP_{c1}}{PGDP_{i}} + \frac{PGDP_{c2}}{PGDP_{i}} \right) /2 \\
GAP_{cj} = \frac{\sum_{i=1}^{n} GAP_{pi}}{n}
\end{gathered} \tag{2}
$$

The economic development gaps between peripheral cities and core cities in single core provinces and double core provinces, as well as the economic development gaps between peripheral cities and central cities, are referred to as the $\text{Coordinate}_{\text{pi}}$ and $\text{Coordinate}_{\text{ci}}$, respectively. $PGDP_{\text{cj}}$ among them is the GDP per capital of core city j in an area, and $PGDP_{\text{pi}}$ is the GDP per capital of city i in each province except the provincial core cities. This paper eliminates the urban samples from four municipalities directly under the central government, namely, Beijing, Tianjin, Shanghai, and Chongqing, as well as the urban samples from eight provinces and autonomous regions in China, including Hainan, Qinghai, Tibet, Xinjiang, Ningxia, and Hong Kong, Macao, and Taiwan. The samples contain 270 prefecture-level cities in mainland China after eliminating the prefecture-level cities whose administrative divisions were changed during the inquiry period.

3.2.2. Explanatory Variables

A method to calculate the process of high-speed railway opening (HSR) is given in Equation (3).

$$HSR_{it} = Year_{it} \times City \tag{3}$$

where "*Year*" represents the time dummy variable. In particular, 1 is taken for the year of high-speed railway opening; otherwise, 0 is taken. *"City"* is the city dummy variable, and 1 is taken for the city with high-speed railway opening; otherwise, 0 is taken. The difference between the economic consequences of the opening of the high-speed rail on the treatment group and the control group—i.e., the impact of the high-speed rail's opening on regional coordinated development—is the interaction term between the two dummy variables. The percentage of high-speed rail cities that were open to the entire sample over the sample observation period rose from 12% to 70%, demonstrating that the sample chosen by the research can accurately track the growth of China's high-speed rail.

3.2.3. Control Variables

Industrial structure (Structure): The city's industrial structure is measured by the proportion of labor employed by the secondary and tertiary industries. Human capital level (Education): expressed as the number of people who went to college per ten thousand people. Material capital investment (Capital): The proportion of fixed assets in GDP is used to measure urban material capital investment. Marketization degree (Market): The marketization index constructed by Fan et al. (2011 [42]) is used to characterize the marketization degree of the city. The year-end represents the population size (Population): the registered population of the municipal district. Table 1 reports the descriptive statistical results of the above variables.

Table 1. Descriptive statistics of variables.

Variables	Mean Value	Standard Deviation	Minimum Value	Maximum Value
lnGAP	0.750	0.543	−4.695	4.899
lnstr	−0.217	0.431	−2.032	1.596
lnedu	−4.669	1.097	−9.738	−2.032
lncap	−0.397	1.458	−6.847	6.476
lnmar	2.309	0.276	1.111	2.953
lnpop	5.729	0.894	1.549	6.780

Figure 1 is the kernel density trend of the economic development gap between “core–periphery” cities. From the perspective of distribution location, the peak of the curve shows a trend of left shift and a right shift in 2006~2011 and 2011~2019, respectively, which indicates that the regional economic development has shown an increasing trend of imbalance after 2011. The left side of the peak is narrowing, and the height of the peak has increased significantly, which shows the widening trend of the economic development gap between the cities originally distributed on the left and the core cities, thus, increasing the polarization of economic development in the region.

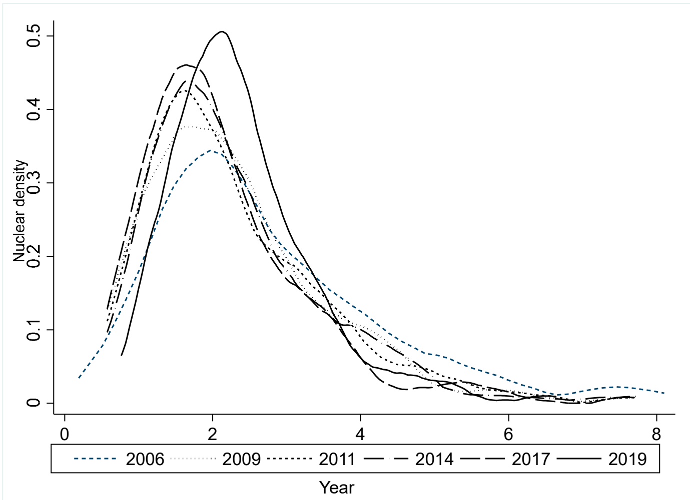

Figure 1. Kernel Density Trend in Economic Development Gap between Core and Peripheral Cities.

3.3. Data Source

Due to the availability of available data, this paper selects 270 prefecture-level cities in mainland China from 2006 to 2019 as samples for empirical testing. Full-text data are primarily taken from the “China City Statistical Yearbook”, Urban Statistical Yearbook, and the National Bureau of Statistics. The results of the descriptive statistics found that the mean values of coordinate (0.750), market (2.309), and population (5.729) are positive. While the mean values of structure (−0.217), education (−4.669), and capital (−0.397) are negative.

4. Results and Discussion

4.1. Baseline Regression Analysis

The regression results for the multiperiod DID model are presented in Table 2. Results found that after appending the control variables, the core explanatory variable (HSR) coefficient is significantly positive. That is, the economic development gap between the “core–periphery” cities of the high-speed railway opening cities is expanded considerably by 0.027 compared with the non-opening cities, indicating that the high-speed railway’s operation strengthens the “siphon effect” of the core city. There is an “aisle effect” on the peripheral cities, thus, exacerbating the in-coordination of the economic development of "core–periphery" cities, which supports Hypothesis 1b. The reasons may lie in the following two points: First, opening an urban high-speed railway reduces the cost of information exchange and communication between enterprises, thus, accelerating the cross-regional flow of capital elements along the high-speed railway network. However, as a matter of common knowledge, capital elements tend to flow to areas with high capital returns, which, in turn, causes the siphon of capital elements from core cities to peripheral cities. Second, the flow of labor factors is similar to that of capital factors. The perfect industrial system and huge economic volume of the core city provide good employment opportunities and development prospects for the labor force, thus, attracting the labor force of peripheral cities to flow into the core city relying on the high-speed railway network. Due to the "siphon effect" being strengthened by the high-speed railway's operation, the core cities are still in the stage of factor endowment improvement, which hinders the relocation of mature technology enterprises. In contrast, the non-core node cities along the high-speed railway are due to the loss of production factors, which makes the regional economic development fall into the "Matthew trap".

Table 2. Results of multi-period DID benchmark regression.

Variables	All Samples		Eastern Region Samples	Central and Western Region Samples
	(1)	(2)	(3)	(4)
HSR	0.030 **	0.027 *	0.059 ***	−0.015
	(2.12)	(1.88)	(2.82)	(−0.82)
lnstr		0.163 ***	0.114 ***	0.159 ***
		(7.22)	(2.65)	(4.30)
lnedu		−0.005	−0.017	0.029 *
		(−0.54)	(−0.52)	(1.82)
lncap		0.007	0.046 **	−0.016
		(0.66)	(2.41)	(−0.92)
lnmar		−0.066	0.232 **	−0.026
		(−0.97)	(2.02)	(−0.28)
lnpop		−0.402 ***	−0.384 ***	−0.235
		(−4.12)	(−3.23)	(−1.25)
Constant	0.738 ***	3.216 ***	2.541 ***	2.485 **
	(105.31)	(5.43)	(3.13)	(2.10)
City	YES	YES	YES	YES
Year	YES	YES	YES	YES
N	3780	3780	1358	896
R^2	0.819	0.823	0.861	0.858

*, ** and *** represent significance level of parameters at 10%, 5%, and 1%, respectively. *t* values are given in the parentheses.

The model in Table 2 (column 3 and 4) represents that the coefficient for estimating high-speed railway's operation is significant in eastern China, but in the central and western regions, they are not significant, that is, the high-speed railway opening only forms a "Matthew effect" on the economic development of "core–periphery" cities in the eastern region, which manifests itself as a barrier to the coordinated development of the urban economy. The possible reason is that the density of the high-speed railway network in the central and western regions and the economic base are also quite different from that in the eastern region, so the advanced elements of the high-speed railway opening cities in the regions of central and western may choose to flow along the existing high-speed railway network to the eastern region, thus, weakening the "siphon effect" and "radiation effect" of the core cities in the central and western provinces.

The current study learned from the causal stepwise regression method of Baron and Kenny (1986) [43] and the method of Wen et al. (2004 [44]) to test the mediating effect and developed the equations 4 to 6 to test the mediating effect to verify the mediating effect of economic agglomeration and technological progress in the effect of high-speed railway opening on the coordinated development of city economy. The Equation (4) is the same as the direct effect test equations 1 and 5, representing the mediating mechanism. The Equation (6) is the direct effect equation, and the control variables are consistent with the previous text. Among them, the intermediary variable M is economic agglomeration (Agg) and technological innovation (lnInno). Drawing on Lin Boqiang and Tan Ruipeng (2019 [45]), Chang Hong and Wang Jun (2020 [46]), economic agglomeration is indicated by the number of jobs per unit area in the city, and the amount of patent authorization represents the technological innovation level. If it is significant for all β_1, γ_1, and γ_2, the mediating effect verified in this paper is established. If only γ_2is significant, M has a complete mediating effect.

$$\mathrm{lnCoordinate_{it}} = \alpha_0 + \alpha_1 \mathrm{HSR}_{it} + \theta \sum \mathrm{Controls_{it}} + \mu_i + \nu_t + \varepsilon_{\mathrm{it}} \quad (4)$$

$$\mathrm{M_{it}} = \beta_0 + \beta_1 \mathrm{lnCoordinate_{it}} + \theta \sum \mathrm{Controls_{it}} + \mu_i + \nu_t + \varepsilon_{\mathrm{it}} \quad (5)$$

$$\mathrm{lnCoordinate_{it}} = \gamma_0 + \gamma_1 \mathrm{HSR}_{it} + \gamma_2 \mathrm{M_{it}} + \theta \sum \mathrm{Controls_{it}} + \mu_i + \nu_t + \varepsilon_{\mathrm{it}} \quad (6)$$

The estimated results of the mediating effect test of economic agglomeration and technological innovation are shown in Table 3. The high-speed railway's opening (HSR) estimated coefficients are significantly positive, explaining that the high-speed railway is an effective driving force to promote the economic agglomeration (logAgglomeration) and technological innovation (logInnovation) of the high-speed railway city. After the high-speed railway opening and the two intermediary variables are included in the model for regression test, the regression coefficients of the high-speed railway opening are significantly positive.

Table 3. Results of mediation effect.

Variables	(1)	(2)	(3)	(4)	(5)	(6)
	logCoordinate	**logAgglomeration**	**logInnovation**	**logCoordinate**	**logCoordinate**	**logCoordinate**
HSR	0.027 *	0.046 *	0.053 **	0.025 *	0.029 **	0.028 **
	(1.88)	(1.70)	(2.30)	(1.80)	(2.08)	(2.02)
logAgglomeration				0.025 ***		0.016 **
				(2.83)		(2.30)
logInnovation					−0.053 ***	−0.055 ***
					(−5.13)	(−5.30)
Constant	3.216 ***	0.327	−3.898 ***	3.212 ***	3.009 ***	2.997 ***
	(5.43)	(0.23)	(−4.04)	(5.43)	(5.09)	(5.07)
Controls	YES	YES	YES	YES	YES	YES
City	YES	YES	YES	YES	YES	YES
Year	YES	YES	YES	YES	YES	YES
N	3780	3780	3780	3780	3780	3780
R^2	0.823	0.603	0.945	0.824	0.825	0.825

*, ** and *** represent significance level of parameters at 10%, 5%, and 1%, respectively. t values are given in the parentheses.

The regression coefficients for the impact of economic agglomeration and technological innovation on the "core–periphery" urban economic development gap are 0.025 and 0.053, respectively, both of which pass the 1% significance level test, i.e., economic agglomeration and technological innovation are found to inhibit and promote the coordinated development of the urban economy, respectively. These results show that economic agglomeration and technological innovation are intermediaries in the high-speed railway opening pathway affecting coordinated regional development. However, the intermediate effect of technological innovation is presented as a masking effect, i.e., the level of urban technological innovation improvement may weaken the inhibiting effect of high-speed railway operations on coordinated regional development, which verifies hypotheses 2 and 3. The reason may be that high-speed railway improved the level of economic agglomeration of core cities through the adjustment of urban industrial structure and the improvement in the allocation of factors between industries, thereby reinforcing the "siphon effect" of the core cities and resulting in the loss of advanced factors of production in the peripheral cities. In the end, shaping the course of core city economic development at the expense of harm to the interests of periphery cities led to increased regional economic development differentiation. Additionally, the human capital allocation effect formed by the improvement in the high-speed railway network in the region helps to elevate the core city's level of innovation, while technological spillovers between node cities connected by the high-speed railway network further boost the economic vitality of edge cities, thereby fostering the coordinated development of urban economies. To test for differences in the efficacy of the two mediating variables established in this study, based on the regression results from Equation (6) of Table 3, calculating that 1.49% and 8.72% of the total effect are due to the mediating effects of economic agglomeration and of technological innovation, respectively, indicating that the asking effect of technological innovation is stronger than the mediating effect of economic agglomeration, i.e., there is a large difference in the economic efficiency of the two channels of transmission.

4.2. Robustness Test

4.2.1. Parallel Trend Test

To guarantee that there are no systematic differences between the experimental and control groups prior to the occurrence of the policy shock, the double difference technique is predicated on the idea that the treatment and the control groups must pass the test for parallel trends. Since Equation (1) is based on the practice of Jin (2013 [47]) in the year prior to the high-speed railway's operation, this study makes reference to Jin's methodology. According to Jin (2013 [47]), tail reduction on both sides is used to generate the policy variables for each year during the six years prior to and seven years following the high-speed railway's operation. The specific regression model is represented by Equation (7) as follows:

$$\text{lnCoordinate}_{it} = \beta + \sum_{t=-6}^{t=7} \varphi_t \text{HSR}_{it} + \gamma \text{Controls}_{it} + \mu_i + \nu_t + \varepsilon_{it} \quad (7)$$

Figure 2 illustrates the outcomes of the parallel trend test of the high-speed railway's operation. The graph demonstrates that the predicted coefficients of the economic impacts prior to the high-speed railway's opening are small and subject to severe changes. The quasi-natural experimental and control groups met the parallel trends test's prerequisite, proving the accuracy of the DID estimate results. The calculated coefficients often show a stronger beneficial impact and a rising trend following the high-speed railway's operation, suggesting that the DID benchmark estimation results have real-world application.

4.2.2. Placebo Test

To confirm that the empirical results are a result of the high-speed railway opening, we performed a counterfactual test using the main explanatory variables 1 to 3 periods in advance as the "wrong opening time". Let us assume that the main explanatory variable coefficient is still important. In that circumstance, aside from the high-speed railway's operation, additional unobserved elements will also have a significant impact on regional coordinated development. If not, it demonstrates that the high-speed train operation's external shock is the cause of the benchmark regression result. The primary explanatory factors did not pass the significance test after 1–3 years prior to the high-speed railway's opening date, as evidenced by the regression results of Table 3 (models 1–3), demonstrating the validity of the empirical findings.

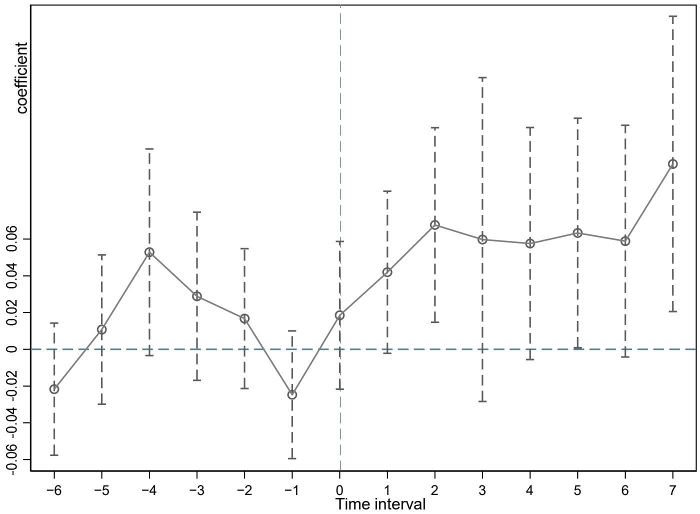

Figure 2. Results of parallel trend test before and after the high-speed railway's operation.

4.2.3. PSM-DID Test

Given that the high-speed railway's site is impacted by urban economic development, resources, and the environment, its operation in cities is not random. This work leverages the control variables mentioned above as matching covariates, employing the nearest neighbor matching approach for propensity score matching, and extends the multi-period DID model discussed above to the multi-period PSM-DID test for robustness. As demonstrated in Figure 3, the normalized deviation is much lower after covariate matching, and the applicability test demonstrates that both the groups of treatment and control obtained by PSM satisfy the test of the common trend hypothesis (result request). For a robustness check, it makes sense to employ PSM-DID. Tests of model 4 in Table 4 demonstrate that the opening of the high-speed railway has a significant positive impact on the economic development gap between "center–periphery" cities, i.e., the operation of the high-speed railway obstructs the regions' coordinated development.

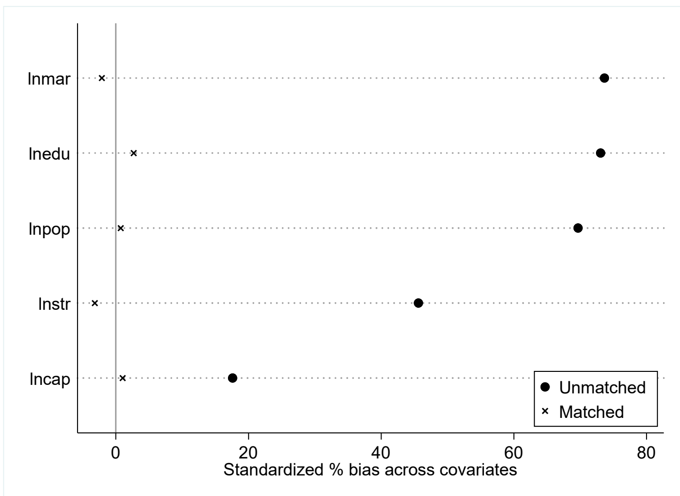

Figure 3. Covariate standardized deviation results before and after propensity score matching.

Table 4. Robustness test.

Variables	(1)	(2)	(3)	(4)
	1 Period Ahead	**2 Periods Ahead**	**3 Periods Ahead**	**PSM-DID**
HSR	0.020	−0.010	−0.014	0.031 **
	(1.39)	(−0.61)	(−1.07)	(1.98)
Constant	3.097 ***	3.266 ***	1.878 ***	0.031 **
	(4.84)	(4.55)	(2.89)	(1.98)
Controls	YES	YES	YES	YES
City	YES	YES	YES	YES
Year	YES	YES	YES	YES
N	3510	3240	2970	3184
R^2	0.835	0.831	0.890	0.821

** and *** represent significance level of parameters at 5%, and 1%, respectively. t values are given in the parentheses.

4.3. Heterogeneity Test

4.3.1. Core–Periphery Urban Spatial Distance Heterogeneity

Due to the "distance dampening effect" of the social and economic effects of the transportation hub, which states that as the distance between peripheral and the central cities in the transportation hub increases, the high-speed rail's radiation and driving effect on the economy of the peripheral cities gradually weakens, the "one-hour metropolitan area" created by the construction of a high-speed railway forms a geographical circle bordered by 200 km. For this reason, in the current study, we followed the approach of Wang K.L. et al. (2021 [8]). Using the latitude and longitude data of each prefecture-level city, we constructed the urban geographical distance matrix, divided the non-core city samples into the "one-hour metropolitan area" urban agglomeration and the metropolitan area urban agglomeration with a distance of 200 km from the core city as the boundary, and performed a group regression. The estimated HSR coefficient in the "one-hour metropolitan area" with the core city as the spatial core is at the 1% level of statistically significant positive (0.058), i.e., the "siphon effect" of the core city raised by the opening of the high-speed railway is increased. In fact, because of the geographical separation between the "core–periphery" cities, the inhibitory effect on the coordinated development of the cities is limited in its usefulness.

4.3.2. Urban Scale Heterogeneity

We split the samples into small and medium-sized cities, large cities, and mega-cities using 1 million and 5 million permanent residents in urban areas as a line of demarcation. Afterward, a group regression was used, as shown in models 3 through 5 in Table 5, in accordance with the most recent State Council recommendations on adjusting urban size division criteria. In small, medium-sized, and large cities, the estimated coefficients for the introduction of high-speed rail are, respectively, significantly negative and positive. It means that the effect of the high-speed railway's opening on the coordinated development of the urban economy has demonstrated that the widening of the economic development gap between large cities and core cities is the primary cause of the regional economic imbalance brought on by the high-speed railway's operation. This finding might be explained by the fact that the opening of high-speed rail lines has a factor reallocation effect that primarily affects cities with abundant production factors and that this effect strengthens the "siphon effect" of core cities on such urban factors by enhancing traffic accessibility between the core cities and the largest cities.

The opening of high-speed railways in smaller cities increases the likelihood of factor inflows from surrounding cities with unopened high-speed railways and spillover effects of knowledge and technology from larger cities and core cities, encouraging the coordinated development of "core–periphery" urban economics. The mega-city regression's coefficient is positive but not particularly significant. The reason for this could be that urban economic development has reached a mature stage of a growth slowdown and megacities have a significant economic volume gap compared to other sizes of cities. For instance, before the high-speed rail opened, megaregions might have developed a quite extensive network of transportation infrastructure. Therefore, despite the high-speed railway's operation, which may hasten the economic growth of megacities, it does not play a significant role.

Table 5. Heterogeneity test.

Variables	(1)	(2)	(3)	(4)	(5)
	(0, 200]	(200, +∞)	Small and Medium Cities	Large Cities	Mega-Cities
HSR	0.058 ***	0.044	−0.272 ***	0.043 **	0.005
	(2.61)	(1.09)	(−2.82)	(2.56)	(0.18)
Constant	3.618 ***	5.057 ***	2.946	6.686 ***	−2.545 **
	(4.27)	(3.83)	(1.61)	(8.09)	(−2.40)
Controls	YES	YES	YES	YES	YES
City	YES	YES	YES	YES	YES
Year	YES	YES	YES	YES	YES
N	1862	658	96	2509	1169
R^2	0.787	0.865	0.938	0.846	0.761

** and *** represent significance level of parameters at 5%, and 1%, respectively. t values are given in the parentheses.

5. Conclusions and Policy Implications

The study estimated the impact of the high-speed railway's operation on the coordinated economic development of "core–periphery" cities using a multiperiod DID model. The high-speed railway's opening is found to exacerbate the "siphon effect" of the province's core cities on its peripheral cities, leading to an even greater disparity between their levels of economic development. This, in turn, inhibits the coordinated growth of "core–periphery" cities' economies. The test for heterogeneity based on the "core–periphery" urban spatial distance and urban size found a negative influence from the high-speed railway's operation on the coordinated development of the urban economy.

The economic impact of the opening of the high-speed rail depends on the size of the city. The operation of the high-speed railway also increased the economic development gap between major and core provincial cities, but it decreased the difference between small and medium cities and core cities. The "core–periphery" development of the urban economy is influenced by economic agglomeration, which plays a middle role in the high-speed railway's functioning. Technology innovation's mediating influence is further demonstrated as a masking effect. It indicates that the operation of the high-speed railway has an economic agglomeration effect that hinders the growth of the "core–periphery" urban economy. However, this effect can be counteracted by increasing the level of innovation in the cities, which would speed up coordinated urban economic growth.

We suggested the following policy implications based on the study's conclusions. First, the high-speed railway's spatial layout needs to be coordinated and upgraded. Second, a high-speed rail network must be developed more quickly depending on local conditions, and the construction of the network should give small and medium-sized cities the proper amount of attention. Third, under the unified leadership of the central government, the governments at all levels should enhance the industrial transfer mechanism and direct key cities to optimize the design of industrial space and industrial transformation and upgrading. Fourth, provincial non-core cities must make efficient use of the "human capital allocation effect" of high-speed rail and raise the standard of a "core–periphery" urban economy.

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