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Does High-Speed Railway Promote the Level of Human Capital? An Empirical Analysis Based on Three Urban Agglomerations in China

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Abstract: This paper analyzed the impact of high-speed railway (HSR) construction on human capital and its mechanism by establishing high-speed railway-city level panel data from 2003 to 2019 and constructing a multiperiod difference- in-differences (DID) DID model in China. The results showed that HSR has significantly promoted the level of human capital in Beijing–Tianjin–Hebei urban agglomeration, Yangtze River Delta urban agglomeration, and Pearl River Delta urban agglomeration in China, with the overall effect value of 20.8%. The conclusion that HSR promotes the level of human capital is still valid through endogenous treatment of the instrumental variable method and robustness test. Further analysis showed that the impact of HSR construction on the level of human capital in urban agglomerations is mainly through the labor mobility and education investment potential, with the effect values of 3.65% and 4.44%, respectively. The findings of this paper highlight the importance of exploiting the external utility of HSR, improving the level of regional human capital, and promoting high-quality economic development of urban agglomerations.

Keywords: high-speed railway (HSR); human capital; labor mobility; education investment potential; urban agglomerations

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1. Introduction

Transportation infrastructure has been regarded by scholars as an important resource and prerequisite for regional economic development (Garrison and Souleyrette, 1996; Donaldson, 2018; Banerjee and Qian, 2020) [1–3]. Many countries have experienced economic explosive growth in the past decades due to the development of railway networks, such as the United States (Donaldson and Hornbeck, 2016) [4], Sweden (Berger and Enflo, 2017) [5], and China (Banerjee et al., 2020) [3]. In recent years, the Chinese government has encouraged the rapid development of high-speed railways (HSR). By the end of 2021, China had 40,000 km of HSR in operation, ranking first in the world. Meanwhile, the HSR network has covered 94.7% of cities with a population of over 1 million. With its punctuality, comfort, safety, and fast speed, HSR improves the accessibility between two or more regions, strengthens the connection between cities, and changes the spatial allocation of factor resources.

Human capital, the source of innovation and development in cities, is a key factor in a country's economic growth (Jayawarna et al., 2014) [6], and its spatial distribution basically determines the spatial distribution of population and economy of a country. With the rapid development of HSR, while promoting face-to-face communication and information dissemination, HSR has also become an important carrier of human capital flow.

A large number of studies have analyzed the impact of HSR on human capital from the prefecture and city level. The existing studies have shown that on the one hand, the opening of HSR can enhance the connection between cities, accelerate the flow of human capital, and promote the dissemination of information and knowledge spillovers at the face-to-face level (Catalini et al., 2016; Wang and Ni, 2016) [7,8], which is conducive to human capital

improvement and urban economic development, and on the other hand, although the opening of HSR can alleviate the problem of human capital mismatch, it has changed the original equilibrium of transportation and triggered the siphoning effect; thereby, more and more human resources flow to the metropolis, forming a "reverse aggregation of human capital" phenomenon, which is not conducive to the development of human capital in peripheral cities in urban agglomeration (Sánchez-Mateos and Givoni, 2012; Monzón et al., 2013; Qin, 2017) [9–11].

However, few studies have focused on the impact of HSR on human capital in urban agglomerations. As the main agglomeration of resource elements and the strongest carrier of collaborative innovation, urban agglomerations play a core supporting role in regional and national economic and social development (Fang, 2015) [12]. Therefore, it is valuable to take urban agglomerations as research samples. Based on the preliminary analysis of literature, this paper raises two questions: (1) Can HSR improve the human capital level of urban agglomerations? (2) What are the mechanisms and ways to enhance the development of human capital in urban agglomerations? Answering these two questions is of great practical significance to bring the external utility of HSR into play more effectively, improve the level of regional human capital, and promote the high-quality economic development of urban agglomerations. Therefore, this paper attempted to employ high-speed railway city-level data from 2003 to 2019 to explain the above two questions through a multiperiod DID model to fill the literature gap.

The main contributions of this study are as follows: This paper (1) measured the direct and indirect effects of HSR on human capital by selecting two mediating variables—labor mobility and education investment potential. The empirical results showed that education investment potential has the greatest promotion effect, while labor mobility has a limited effect. The implication is that local governments should attach importance to economic development and strengthen education security. (2) We used the large sample data of education expenditure per student to test the indirect impact of HSR on human capital from the perspective of education investment, which enriches the related research on human capital and provides useful insights in further giving play to local advantages, attracting talents to work, and stimulating the vitality of human capital. (3) We took the three major urban agglomerations in China as research samples and found that the impact of the opening of HSR on the human capital of the three major urban agglomerations is heterogeneous. By putting forward relevant policy suggestions based on the specific conditions of the three major urban agglomerations, we contribute to the realization of the economic development model of "HSR + urban agglomeration" and the promotion of high-quality coordinated development of the regional economy.

The rest of this article is organized as follows. The second part puts forward a literature review and hypothesis development. The third part details the methodology. The main results and discussions are shown in the fourth part. Part five presents the robustness test. The mechanism analysis is shown in the sixth part. The final part provides brief conclusions and recommendations are shown in the seventh part.

2. Literature Review and Hypothesis Development

2.1. Literature Review

2.1.1. The Direct and Indirect Impact of HSR on the Level of Human Capital

In the existing literature, scholars have mostly studied the direct and indirect effects of HSR on human capital levels. In terms of direct impact, on the one hand, HSR has significantly improved the efficiency of human capital allocation in cities along the route through the flow of human capital and the expansion of market scale (Lin, 2017) [13]. This is mainly reflected in improving the distance accessibility of individuals to search for jobs (Coto-Millán et al., 2007) [14] and making their employment choices more flexible. At the same time, it provides opportunities for enterprises to hire more high-quality talent, which is conducive to enhancing the soft power of enterprise development (Yang et al., 2021) [15]. On the other hand, HSR directly promotes the quality of human capital.

This is mainly manifested in the fact that HSR facilitates face-to-face communication and information dissemination (Kobayashi and Okumura, 1997) [16], promotes knowledge spillover between regions (Vickerman, 2015; Aldieri et al., 2018) [17,18], and is conducive to technological innovation of enterprises (Acemoglu et al., 2016) [19].

In terms of indirect impact, the opening of HSR can affect the development of human capital through economic growth, environmental governance, and health care. First, investment in HSR will directly drive regional economic growth through the investment multiplier effect (Alumni et al., 2013) [20]. Economic growth means an increase in job opportunities, remuneration packages, and high-quality labor market demand, making the market more attractive to high-quality talent (Ahlfeldt and Feddersen, 2018) [21]. Second, studies have shown that air pollution can cause negative emotions in individuals, reduce cognitive ability, damage physical health, and reduce human capital output (Hanna and Oliva, 2015; Ebenstein et al., 2016; Chen et al., 2016) [22–24]. However, as one of the low-energy consumption and high-clean transportation modes, HSR not only has a significant air pollution control effect (Chang et al., 2019; Yang et al., 2019) [25,26], but also facilitates the transfer of human capital to HSR cities with lower air pollution (Kamga and Yazici, 2014) [27]. Third, human capital refers to the capital of laborers, such as knowledge and skills, cultural and technical level, and health status, etc. It formed through human investment, such as education spending, health care spending, and labor domestic mobility spending. However, the opening of HSR can improve the accessibility of medical resources and accelerate the flow and aggregation of medical resources, which is beneficial to the improvement of resident's health (Bell and Dillen, 2018; Wang et al., 2020) [28,29].

2.1.2. Review of Existing Studies

By reviewing the existing literature, we found the following shortcomings of the related research. (1) Sample selection: there are many studies focus on cities at the provincial or prefecture-level, ignoring the comparison and heterogeneity analysis of urban agglomerations as research samples. As a product of economic development, scholars focus on HSR mainly on regional economic growth (Ke et al., 2017) [30], enterprise productivity (Cairó and Cajner, 2018; Bernard et al., 2019) [31,32], and international trade (Xu et al., 2017) [33]. However, there is a lack of selecting urban agglomerations as research samples. In addition, the literature on the human capital of urban agglomerations is scarce. (2) Impact analysis: existing research focuses on the direct effect of HSR on human capital, and lacks the indirect effect analysis with education as the main line. Most of the existing literature uses the flow of human capital to analyze the impact of HSR on solving human capital employment (Lin, 2017) [13] and human capital allocation (Wang et al., 2020) [34]. Few scholars have paid attention to the changes in the level of human capital brought about by the impact of HSR on human investment. The most important point is that education, as one of the key elements of human investment, has a reverse causal relationship with economic growth (Bils and Klenow, 2000) [35], and it is bound to have an impact on human capital through the economic effect of HSR.

Therefore, based on the sample data of China's three major urban agglomerations, Beijing–Tianjin–Hebei urban agglomeration, Yangtze River Delta urban agglomeration, and Pearl River Delta urban agglomeration from 2003 to 2019, this paper adopted a multi-period DID model to empirically test the impact of the opening of HSR on the level of human capital. Based on the two main lines of labor mobility and education investment potential, it specifically analyzed the two paths and mechanisms of the impact of HSR on human capital.

2.2. Hypothesis Development

The new economic geography theory incorporates transportation costs into the theoretical analysis framework and introduces spatial distance into the economic model. It points out that the decline in transportation cost will bring about agglomeration effect and accelerate the flow of factors and industrial agglomeration, thereby generating economies

of scale, and achieving increasing returns to scale, further promoting economic growth (Krugman,1991) [36]. The theory of external spillover effects of human capital believes that the accumulation of human capital has positive external spillover effects, especially the agglomeration of high-level human capital (Glaeser, 2018) [37]. HSR with the effect of "space-time compression" can reduce the geographical friction between cities, and improve the allocation efficiency of human capital by reducing transportation costs and time costs. The decrease in the cost of face-to-face communication is conducive to the accumulation of high-quality human capital, resulting in knowledge spillover effects, and further promoting the improvement of human capital levels. For a long time, the uneven distribution of human capital resources between regions and within regions has set up certain obstacles for development of regional human capital; HSR can shorten the temporal and spatial distance between cities. On the one hand, it improves the distance accessibility of human capital to search for jobs (Coto-Millán et al., 2007) [14] and increases employment opportunities for human capital in terms of quality and quantity. By improving the allocation efficiency of human capital, it can promote the development of enterprises and human capital level. On the other hand, it breaks the restrictions on the spatial flow of talents, promotes the flow of human capital and knowledge spillover, and strengthens the educational integration between regions by hiring qualified teachers and experts from inside and outside the province to give lectures and cooperation on projects of different universities or scientific research institutions. With the flow of human capital and the spatial overflow of knowledge, the impact on regional scientific research level and innovation capability far exceeds the effect brought by online sharing and remote communication. Offline communication is still one of the main effective ways of knowledge sharing (Von Hippel, 1994) [38]. Based on the above analysis, this paper proposes the following research hypotheses:

Hypothesis 1 (H1). *By accelerating the flow and agglomeration of human capital, HSR will generate a human capital allocation effect and knowledge spillover effect, thereby promoting the improvement of regional human capital level. (Direct impact)*

As a representative of human capital theory, Schultz (1993) [39] regards human labor capacity as a kind of capital that can provide benefits. The benefits of human capital far exceed physical capital, and education is an important source of human capital investment. Therefore, economic development should pay attention to investment in education. The relationship between economic growth and education is as follows: on the one hand, economic growth requires education to provide a large number of workers with technical and cultural proficiency. On the other hand, the development of education is constrained by a country's financial resources, and sustained economic growth provides a guarantee for education funding. By forming spatial agglomeration and economies of scale, HSR promotes the economic growth of cities along the line, laying a solid material foundation for the government and residents to invest in education development, thereby contributing to the improvement of human capital. Specifically, the investment in the construction of HSR has a multiplier effect, which directly stimulates economic growth by driving employment and output in related industries (Chen et al., 2007) [40]. By accelerating the inflow of production factors such as capital, labor, and technology to the HSR cities, the division of labor and cooperation based on the education industry chain in the cities along the line has been strengthened. In addition, HSR promotes economic growth, and is conducive to the cultivation and development of education, which is an important guarantee for the improvement of human capital. On the one hand, economic development makes it possible to increase investment in public education. Numerous studies have shown that the economy is the most important and lasting factor affecting and restricting the development of education. Government financial appropriation is still the main source of funding for most colleges and universities in China (Zhu and Wang, 2010) [41]. On the other hand, economic development has brought about the increase of residents' incomes and the enhancement of educational investment capacity. The income of residents not

only affects the demand for education but also directly affects the supply of education. In a word, the improvement of education investment potential will help residents to obtain better educational resources and opportunities, thereby promoting the improvement of human capital level. Based on the above analysis, this paper proposed the following research hypotheses:

Hypothesis 2 (H2). *HSR promotes regional economic growth, and, by increasing the potential of education investment, produces an education security effect that is conducive to the development of human capital. (Indirect impact)*

In addition, the human capital flow and education guarantee effect caused by the opening of the HSR are heterogeneous in the improvement of human capital, will have different impacts on different urban agglomerations based on the combined effect of the superposition of the siphon effect and the diffusion effect. Therefore, the final impact of the opening of HSR on the human capital level of urban agglomerations needs to be studied and tested through measurement methods. A summary of the impact mechanism of HSR on human capital is shown in Figure 1.

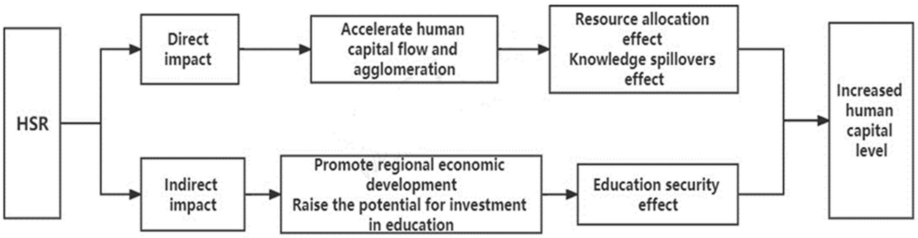

Figure 1. The impact mechanism of the opening of HSR on human capital.

3. Methodology

3.1. Sample Selection and Data Sources

The research selected in this paper was the balanced panel data of 50 cities in China's three major urban agglomerations—Beijing–Tianjin–Hebei urban agglomeration, Yangtze River Delta urban agglomeration, and Pearl River Delta urban agglomeration from 2003 to 2019. Due to the unavailability of data, this paper excluded 7 cities including Taizhou, Wuhu, Xuancheng, Hengshui, Dingzhou, Xinji, and Anyang. See Table 1 for details.

Table 1. The constituent cities of the three major urban agglomerations.

Urban Agglomeration	Number of Cities	City Name
Beijing–Tianjin–Hebei	12	Beijing, Tianjin, Baoding, Tangshan, Langfang, Shijiazhuang, Qinhuangdao, Handan, Xingtai, Zhangjiakou, Chengde, Cangzhou
Yangtze River Delta	23	Shanghai, Nanjing, Wuxi, Changzhou, Suzhou, Nantong, Yancheng, Yangzhou, Zhenjiang, Hangzhou, Ningbo, Shaoxing, Huzhou, Jiaxing, Jinhua, Zhoushan, Taizhou, Hefei, Maanshan, Tongling, Anqing, Chuzhou, Chizhou
Pearl River Delta	15	Guangzhou, Shenzhen, Foshan, Dongwan, Zhongshan, Huizhou, Zhuhai, Jiangmen, Zhaoqing, Shaoguan, Yangjiang, Shanwei, Heyuan, Qingyuan, Yunfu

The HSR-related data come from the website of China Railway Corporation, the relevant announcements of the Railway Administration and the 12306 Website, and the rest of the data comes from the "China Urban Statistical Yearbook", "Provincial (City, District) Statistical Yearbook (2004–2020)", and "China Regional Economy Statistical Yearbook". Missing data were completed by interpolation.

3.2. Variable Definition

3.2.1. Dependent Variable

Regional human capital level (Lnhc) in this paper refers to the human capital with high skills (this paper assumes that the labor force has a healthy body). In recent years, we found that the proportion of college students is mostly used as a measure of urban human capital level (Moretti, 2004; Berry and Glaeser, 2005; Diamond, 2016; Liang and Lu, 2019) [42–45]. Some scholars conducted a correlation coefficient test between the variable of college students per 10,000 people and the logarithm of the average years of education in each city and the population with a college degree or above, published in the "2010 National Census Information by County", and found that the correlation coefficients are respectively 0.6140 and 0.6352, indicating that ratio of college students per 10,000 people maintain a relatively high level of correlation with the average years of education and the population with a college degree or above in the region. Therefore, this paper selected the ratio of college students per 10,000 people to measure the regional human capital.

3.2.2. Independent Variable and Mediating Variables

High-speed railway (HSR) is the independent variable. It is measured by whether there are high-speed rail stations in the area. Since the impact of the high-speed rail put into operation often has a certain time lag, this paper adjusted the specific time of the high-speed rail in each city as follows. If the operation time of the high-speed rail line in the city is between January and June, the high-speed rail dummy variable takes the value of "1" in the current year; if the operation time is between July and December, the variable takes a value of "1" in the next year, and a value of "0" in the current year.

There are two mediating variables in this paper. (1) Labor mobility (Laborflow): the measurement of human capital mobility is the same as that of labor mobility. Considering the availability of data, this paper used labor mobility as an intermediary variable. We refer to the study of (Bai et al., 2017) [46] and used a gravity model to measure labor mobility, including two important factors that affect labor mobility: wages and housing prices. The specific model is as follows:

$$Labor\_flow_{ij} = lnLabor_i \cdot \ln(Wage_j - Wage_i) \cdot \ln(House_i - House_j) \cdot R_{ij}^{-2} \quad (1)$$

$$Labor\_flow_i = \sum_{j=1}^{n} Labor\_flow_{ij} \quad (2)$$

In model (1), $Labor\_flow_{ij}$ is the flow of labor from city i to city j, $Labor_i$ is the amount of labor force in city i, $Wage_j$ and $Wage_i$ represent the average wages of employed workers in city j and city i, respectively. $House_i$ and $House_j$ represent house prices in city i and city j, respectively. The house prices are expressed by the average sales price of residential commercial housing. R_{ij} is the geographic distance between city i and city j, calculated based on the latitude and longitude data of the two cities. Model (2) represents the total labor flow of city i in the statistical year.

(2) Education investment potential (Lnsedu): taking into account the availability and representativeness of the data, this paper selected the education expenditure per student to measure, which was obtained by dividing the local fiscal education expenditure by the number of local students.

3.2.3. Control Variables

(1) Industrial structure (Lnstrc): this paper measured the industrial structure with the comprehensive index of industrialstructure. The comprehensive index of industrial structure = the proportion of primary industry + 2 × the proportion of secondary industry + 3 × the proportion of tertiary industry.

(2) Financial level (Finance): the city's financial development level will influence low-income group to increase educational expenditures to afford high-level educational expenses by lowering the personal credit threshold and broadening educational loans, thereby realizing the accumulation and improvement of human capital. This paper selected

the proportion of end-of-year loan balance of financial institutions of each city to the city's gross domestic product.

(3) Foreign direct investment (FDI): FDI can effectively acquire foreign advanced technology and knowledge, which is conducive to the accumulation and improvement of human capital. This paper selected the proportion of the actual utilization of foreign capital in each city to the city's GDP, and converted it at the average exchange rate of RMB against the US dollar in that year.

(4) Basic education (Lnedu): the skills and knowledge acquired at the individual level at the foundation stage play a crucial role in acquiring higher human capital in the future. This paper used the number of middle school teachers per 10,000 people to measure.

(5) Technological progress (Rd): human capital is an essential element of technology research and development (R&D) activities, and new technologies have created opportunities for the accumulation and promotion of human capital. This paper used the ratio of R&D investment to regional GDP to measure.

3.3. Model Construction

Econometric Model

This paper first used the panel data of Beijing–Tianjin–Hebei, Yangtze River Delta, and Pearl River Delta from 2003 to 2019 to build Multi-stage DID models to analyze the impact of high-speed rail construction on human capital. Then, the empirical results of this paper were tested for robustness by means of parallel trend test, endogeneity test, placebo test, and alternative key variables. Finally, we performed a mechanism analysis to test the two hypotheses of this paper from the two aspects of labor mobility and education investment potential. Figure 2 presents the logic of model construction.

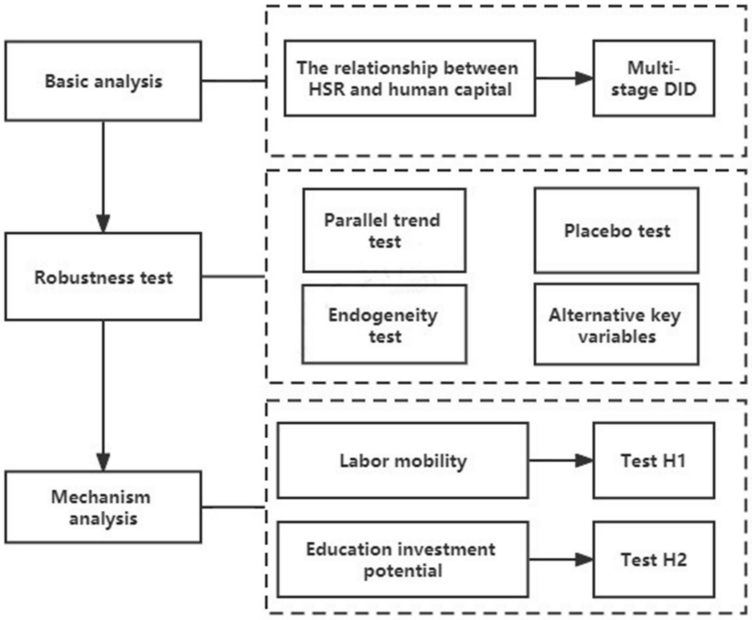

Figure 2. The logic roadmap of the model construction.

(1). Benchmark Regression: Multiple DID Model

The opening of the HSR will impact human capital and have the following effects. On the one hand, natural changes are brought about by the passage of time and the development and changes of economic trends, which can be called the "time effect". On the other hand, there are changes brought about by the opening of HSR, which is called the "treatment effect". Based on the above analysis, the opening of the HSR can be regarded as a quasi-natural experiment, and the multi-period DID can be used to distinguish the "time effect" and "treatment effect" brought by the opening of the HSR. In this way, the net impact

of the opening of the HSR on the human capital of the three major urban agglomerations in China can be accurately assessed. The model was set as follows:

$$lnhc = \alpha_0 + \beta_1 hsr_{it} + \beta_2 control_{it} + \mu_i + \lambda_t + \varepsilon_{it} \quad (3)$$

In model (3), *lnhc* represents the level of human capital in region, *hsr* refers to the dummy variable of whether the HSR is open or not, *control* is the control variable, and μ and λ represent the individual fixed effect and time fixed effect, respectively. ε is the random disturbance term, i represents the city, and t indicates the year. β_1 is the coefficient that this paper focuses on, which represents the impact of the opening of HSR on the human capital level of urban agglomerations after removing other interference factors.

(2). Mechanism Analysis

In order to further confirm its existence of the mechanism, this paper refers to the test method of Hayes (2009) [47] to test the mediation effect and used the recursive regression equation. The model settings were as follows:

$$lnhc = \alpha_0 + \beta_1 hsr_{it} + \beta_2 control_{it} + \mu_i + \lambda_t + \varepsilon_{it} \quad (4)$$

$$Z_{it} = \alpha_0 + \lambda hsr_{it} + \varphi control_{it} + \mu_i + \lambda_t + \varepsilon_{it} \quad (5)$$

$$lnhc = \alpha_0 + \beta_3 hsr_{it} + \theta Z_{it} + \phi control_{it} + \mu_i + \lambda_t + \varepsilon_{it} \quad (6)$$

Z is the mediating variable, and other variables have the same meaning as the variables in model (3). The test method of the mediation effect is as follows: first, we estimated the model (4) to test whether the opening of the high-speed rail has a promoting effect on regional human capital. If β_1 is significantly positive, it indicates that the opening of the high-speed rail has a significant positive effect on regional human capital. This paper completed the test in the benchmark regression part. The second step is to regress the model (5) to examine the relationship between the opening of the high-speed rail and the intermediary variable. Finally, the regression to model (6) was performed to test the impact of the opening of the HSR and the intermediary variable on regional human capital. If the values of λ, β_3 and θ were all significantly positive, and $\beta_3 < \beta_1$, it indicated that there was a mediation effect. If at least one of λ and θ is not significant, the Sobel test needs to be performed. If the statistic Z passed the significance test, the mediating effect was significant, where the critical value of the statistic Z value at the 5% significance level was approximately 0.97 (MacKinnon et al, 2002) [48].

4. Main Results and Discussions

4.1. Descriptive Statistics

Table 2 below provides descriptive statistics results for the main variables. Considering the convenient calculation of data, this paper took the logarithm of the relevant complex data value variables, including Lnhc, Lnstrc, Lnedu, and Lnsedu.

4.2. Baseline Regression Results

The baseline regression results of model (3) are presented in columns (1) and (2) of Table 3, respectively. Column (1) contains only explanatory and explained variables, while column (2) further adds control variables. Columns (3)–(5) are the result of Beijing–Tianjin–Hebei urban agglomeration, Yangtze River Delta urban agglomeration, and Pearl River Delta urban agglomeration, respectively. In order to make the estimation analysis more accurate, the city-fixed effect and year-fixed effect in the model were controlled.

Columns (1) and (2) show that coefficients of the variable HSR were significantly positive at the 1% significance level, proving that the opening of HSR has a positive effect on the improvement of human capital in the region, whether the control variables are added or not. Compared with cities without HSR, high-speed rail cities have higher levels of human capital. Further analysis of the control variables shows that (1) industrial structure (Lnstrc) and basic education (Lnedu) play a significant role in promoting human capital in

urban agglomerations. Lnstrc passed the 1% level of significance test, and Lnedu passed the 5% level of significance test. This is consistent with expectations. (2) Foreign direct investment (FDI) has a significant negative impact on regional human capital. This is different from previous research results. It may be because FDI has a competitive impact and crowding effect on innovative enterprises or high-tech enterprises in the city, which has an indirect adverse impact on human capital. (3) Financial level (Finance) and Technological progress (Rd) on human capital in urban agglomerations is not significant.

Table 2. Descriptive statistics.

Variables Type	Variables	N	Mean	Std Dev.	Minimum	Maximum
Dependent Variable	Lnhc	850	4.9418	1.0626	1.8077	7.1471
Independent Variable	HSR	850	0.5129	0.5001	0.0000	1.0000
Control Variables	Lnstrc	850	5.4464	0.0632	5.2578	5.6369
	FDI	850	0.0371	0.0304	0.0007	0.2011
	Finance	850	1.092	0.7105	0.1886	9.0122
	Rd	850	0.0031	0.0038	0.0000	0.0415
	Lnedu	850	3.6908	0.223	1.2461	4.8859
Mediating Variables	Laborflow	850	0.7009	0.4747	0.1081	2.5120
	Lnsedu	850	8.4903	1.2993	1.2301	10.8528

Table 3. Baseline regression results.

	(1)	(2)	(3)	(4)	(5)
Variables			**Lnhc**		
HSR	0.445 ***	0.208 ***	0.218 **	0.091	0.133
	(18.23)	(4.40)	(2.61)	(1.17)	(1.53)
Lnstrc		3.438 ***	1.106	4.038 ***	2.018
		(4.10)	(0.81)	(3.35)	(1.62)
FDI		−2.553 ***	1.009	−0.24	−6.439 ***
		(−2.74)	(0.64)	(−0.30)	(−3.61)
Finance		−0.045	−0.021	−0.129 **	0.05
		(−1.17)	(−0.40)	(−2.30)	(0.53)
Rd		5.302	9.096	25.636 *	−6.236
		(0.67)	(0.52)	(1.85)	(−0.58)
Lnedu		0.464 **	−0.928 ***	0.377	0.713 ***
		(2.43)	(−3.37)	(1.16)	(4.46)
Constants	4.713 ***	−15.478 ***	2.269	−18.166 **	−9.035
	(34.70)	(−3.37)	(0.31)	(−2.66)	(−1.35)
Year and Ind	Controlled	Controlled	Controlled	Controlled	Controlled
N	850	850	204	391	255
R^2	0.292	0.468	0.445	0.425	0.663

***, **, and * represent 1%, 5%, and 10% levels of significance, respectively. *t*-values are presented beneath the coefficient estimates in parentheses.

Columns (3)–(5) show that the coefficients of the variable HSR of the three urban agglomerations are all positive, which further confirms the promotion effect brought by HSR. However, the human capital influence coefficient of the Beijing–Tianjin–Hebei urban agglomeration is 0.218 and passed the significance test at the 5% level. As we all know, this urban agglomeration includes two developed municipalities—Beijing and Tianjin. It is highly dependent on those two core cities in the development process. Therefore, the positive impact of the opening of HSR on the human capital of Beijing and Tianjin plays a pivotal role in the development of the human capital of the urban agglomeration. However, the influence coefficients of human capital in the Yangtze River Delta and Pearl River Delta urban agglomerations are not significant. For Yangtze River Delta urban agglomeration, it is perhaps due to the uneven development between cities in the region,

and the limited radiation and driving effect of the core cities. For Pearl River Delta urban agglomeration, many cities in the region are still lagging behind in terms of development level, such as Shanwei and Heyuan, whose ability to attract resources is insufficient.

4.3. Evolutionary Characteristics Analysis

In order to further analyze the impact of high-speed railway construction on the human capital of the three major urban agglomerations, this paper divided the research period into three stages according to two time points: 2008 and 2013. China entered the high-speed era in 2008 and the mileage of high-speed railways exceeded 10,000 kilometers in 2013, ranking first in the world. The first stage is 2003–2007, the second stage is 2008–2013, and the third stage is 2014–2019. Through the analysis of the three stages, we hope to explore the dynamic evolution characteristics of the impact of high-speed rail on the human capital of the three major urban agglomerations. As can be seen from Table 4, in the initial stage of high-speed rail construction in the first stage, the coverage of the high-speed rail network was low, and the impact on human capital of urban agglomerations was limited. The second stage was the period of substantial construction of the high-speed rail, which had a significant positive impact. At the same time, combined with the results of the benchmark regression, it can be seen that the positive effect of the high-speed rail only existed in this stage. The third stage was the perfect period of high-speed rail construction, when the coefficient was not significant and negative. However, this result does not meet expectations. Combined with the benchmark regression results and further analysis, FDI, Finance, and Rd all had negative effects. Considering the uneven development level of cities in the Yangtze River Delta and Pearl River Delta urban agglomerations, we speculate that the siphon effect of the opening of the high-speed rail increased the level of development between central cities and non-central cities within the urban agglomeration, making the overall human capital level of the urban agglomeration lag behind. This suggests that, if we the high-speed rail to promote human capital in the long-term, we must pay attention to the coordinated development between regions or cities.

Table 4. Evolutionary characteristics analysis results.

	2003–2007	2008–2013	2014–2019
Variables		**Lnhc**	
HSR	−0.047	0.108 **	−0.025
	(−0.51)	(2.36)	(−0.37)
Lnstrc	1.318	1.099	0.863 *
	(0.66)	(0.85)	(1.86)
FDI	−1.51	−2.242	−0.008
	(−1.52)	(−1.15)	(−0.02)
Finance	−0.706 ***	0.230 **	−0.001
	(−4.10)	(2.02)	(−0.05)
Rd	440.278 **	8.352	−0.425
	(2.59)	(0.6)	(−0.13)
Lnedu	0.432	0.343 *	0.012
	(1.15)	(1.72)	(0.23)
Constant	−3.571	−2.444	0.419
	(−0.33)	(−0.34)	(0.17)
Year and Ind	Controlled	Controlled	Controlled
N	250	300	300
R^2	0.457	0.195	0.023

***, **, and * represent 1%, 5%, and 10% levels of significance, respectively. *t*-values are presented beneath the coefficient estimates in parentheses.

5. Robustness Test

5.1. Parallel Trend Test

To test whether the sample in this paper satisfies the parallel trend hypothesis, we refer to the study of Beck et al. (2010) [49] and defined nine years of dummy variables according to the following method. HSR4, HSR3, HSR2, and HSR1 represent 4, 3, 2, and 1 year(s) before the opening of HSR. Current represents the year when HSR opened, and HSRL1, HSRL2, HSRL3, and HSRL4 represent 1, 2, 3, and 4 years after the opening of HSR.

Columns (1) and (2) show the results of three urban agglomerations and Beijing–Tianjin–Hebei urban agglomeration, respectively. The results in Table 5 show that the coefficients of HSR4, HSR3, HSR2, and HSR1 and Current were not significant. HSRL2, HSRL3, and HSRL4 were all significantly and positively related to human capital, indicating that the effect of HSR opening on human capital was significant in the year after opening. These results suggest that HSR opening has a lasting effect on the level of human capital.

Table 5. Parallel trend test.

Variables	(1) Lnhc	(2) Lnhc
HSR4	0.124	0.089
	(3.96)	(1.71)
HSR3	0.075	0.042
	(1.33)	(0.47)
HSR2	−0.007	−0.035
	(−0.14)	(−0.42)
HSR1	0.06	0.128
	(1.18)	(1.62)
Current	0.036	0.025
	(0.71)	(0.33)
HSRL1	0.081	0.09 *
	(0.16)	(1.12)
HSRL2	0.063 *	0.109 *
	(0.27)	(1.25)
HSRL3	0.104 *	0.146 **
	(0.78)	(1.36)
HSRL4	0.221 *	0.281 **
	(1.2)	(2.05)
N	850	204
R^2	0.535	0.541

** and * represent 5% and 10% levels of significance, respectively. *t*-values are presented beneath the coefficient estimates in parentheses.

5.2. Endogeneity Test

A certain endogenous relationship may exist between the opening of high-speed rail and urban human capital. The main reason is that the choice of high-speed rail lines and stations will be affected by urban development factors, such as regional, economic, and social development, as well as strategic transportation status. Because human capital may have a two-way causal relationship with other factors, such as economic growth and location advantages, it will lead to endogeneity problems. If the endogeneity problem is not considered in the research process, it will cause serious bias in the regression results. To further control the endogeneity problem, we selected the topographic relief of the prefecture-level administrative district as an instrumental variable (IV) consistent with the opening of high-speed rail, and used the two-stage least squares (2SLS) method to solve the abovementioned problem.

The basis for selecting topographic relief as the instrumental variable is as follows. On the one hand, topographic relief fully reflects the topographic condition of a specific area and directly affects the cost of HSR construction. Therefore, it satisfies the requirement that the instrumental variables should be correlated. On the other hand, the topographic relief is a natural geographical condition formed in the long history of the region. It exists objectively and is not directly related to the human capital. This indicator satisfies the requirement that the instrumental variables should be exogenous.

The analysis results in Table 6 below show that the estimated coefficient of the high-speed rail opening in column (2) was positive and passed the 1% significance level test, which is basically consistent with the abovementioned results, indicating that the conclu-

sions of this paper are credible. In addition, the statistical value of the F statistic was greater than the 10% level, indicating that the selection of instrumental variables is effective.

Table 6. Regression results of the instrumental variables.

2SLS	First Stage	Second Stage
	(1)	(2)
	HSR	Lnhc
HSR		0.390 ***
		(5.35)
IV	0.015 ***	
	(140.88)	
Control	YES	YES
Constant	0.089 *	0.423
	(1.68)	(0.78)
N	850	850
R^2	0.969	0.264
Cragg-Donald Wald F Statistic	5201.54	

*** and * represent 1% and 10% levels of significance, respectively. *t*-values are presented beneath the coefficient estimates in parentheses.

5.3. Alternative Key Variables

This paper used the average years of education in the prefecture-level administrative district as a substitution variable for human capital in each city to conduct robustness tests. As can be seen in Table 7 below, this paper only listed the estimation results related to the core explanatory variables. Column (1) shows that the opening of the high-speed rail had a significant impact on the three major urban agglomerations (at least at the level of 5%), and the impact of the high-speed rail on the Beijing–Tianjin–Hebei urban agglomeration was significant at the 5% significance level; the impacts on the Pearl River Delta and Yangtze River Delta urban agglomerations were still insignificant, which is consistent with the results of the previous tests.

Table 7. Regression results of alternative key variables.

Variables	(1)	Beijing–Tianjin–Hebei	Yangtze River Delta	Pearl River Delta
	Tedu	Tedu	Tedu	Tedu
HSR	0.378 **	0.605 **	0.043	0.26
	(2.06)	(2.31)	(0.12)	(0.91)
N	50	50	50	50
R^2	0.541	0.588	0.642	0.855

** represents 5% level of significance, respectively. *t*-values are presented beneath the coefficient estimates in parentheses.

5.4. Placebo Test

A placebo test was conducted on the multi-period DID, and the results are shown in Figure 3. Due to the different policy time of different individuals, this paper randomly selected individuals as the treatment group and randomly selected time as the policy time to generate pseudo-policy dummy variables for regression. Figure 3 below shows the distribution of the estimated coefficients of 500 pseudo-policy dummy variables and the corresponding *p*-values, where the *x*-axis represents the size of the estimated coefficients of the pseudo-policy dummy variable, the *y*-axis represents the density value and the *p*-value, the curve represents the kernel density distribution of the estimated coefficients, and the blue dots represent the corresponding *p*-values of the estimated coefficients. It can be seen from the figure that most of the estimated coefficients were concentrated in the range of −1 to 1, the real estimated values of 0.208 and 0.218 were obviously outliers, and the *p*-values of most of the estimated values were greater than 0.1, indicating that there was no

interference of unobservable systematic errors on the estimation results and the baseline regression. Furthermore, the regression results passed the placebo test.

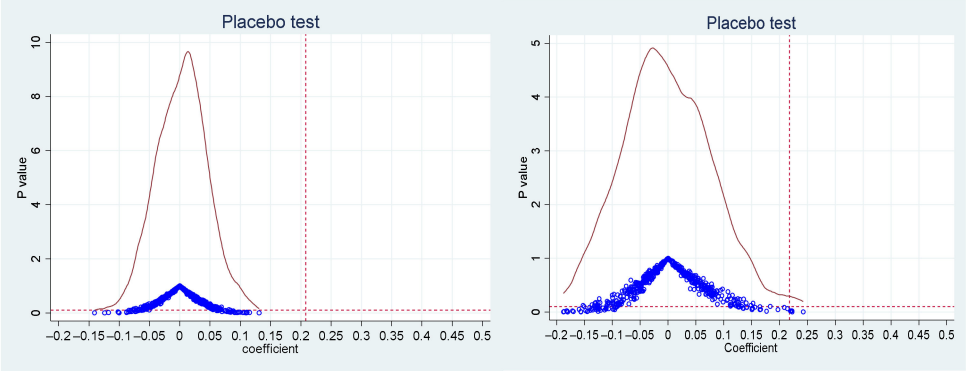

Figure 3. Placebo test of the three urban agglomerations and Beijing–Tianjin–Hebei urban agglomeration, respectively.

6. Mechanism Analysis

From the analysis of the results of the benchmark regression, the opening of the high-speed rail was shown to have a promoting effect on the human capital of the urban agglomeration. However, what kind of dynamic mechanism is at work such that the opening of the high-speed rail promotes regional human capital? As mentioned in the hypothesis development section of this paper, HSR may have an impact on regional human capital through increased labor mobility and education investment potential. The regression results are shown in Table 8.

Table 8. Regression results of the mechanism.

	(1)	(2)	(3)	(4)	(5)	(6)
Mediating variable		Lnsedu			Laborflow	
Dependent variable	Lnhc	Lnsedu	Lnhc	Lnhc	Laborflow	Lnhc
	First stage	Second stage	Third stage	First stage	Second stage	Third stage
HSR	0.208 ***	0.592 ***	0.164 ***	0.208 ***	0.068 ***	0.183 ***
	(4.4)	(4.87)	(3.49)	(4.4)	(4.55)	(3.52)
Z			0.075 ***			0.375
			(3.08)			(1.47)
Control	YES	YES	YES	YES	YES	YES
Constant	−15.478 ***	−73.134 ***	−10.002 **	−15.478 ***	−4.101 ***	−13.941 ***
	(−3.37)	(−7.47)	(−2.09)	(−3.37)	(−2.77)	(−2.89)
Year and Ind	Controlled	Controlled	Controlled	Controlled	Controlled	Controlled
N	850	850	850	850	850	850
R^2	0.468	0.38	0.511	0.468	0.549	0.478

*** and ** represent 1% and 5% levels of significance, respectively. *t*-values are presented beneath the coefficient estimates in parentheses.

From the perspective of education investment potential (mediating variable Z_1), first, the results presented by column (1) show that the opening of the high-speed rail had a significant positive effect on the improvement of regional human capital. Secondly, the results of column (2) show that the estimated coefficient of high-speed rail opening on education expenditure level was significantly positive (with a value of 0.592), indicating that the high-speed rail opening increased the level of regional expenditure on education. In column (3), it can be seen that the influence coefficients of the opening of high-speed rail and the level of education expenditure on the human capital in the region were significantly positive, and the coefficient β_3 (value of 0.164) of the opening of high-speed rail was less than β_1 (with a value of 0.208), indicating that the opening of the high-speed rail will indirectly promote the improvement of regional human capital through the increase of

education expenditure level. Specifically, under the premise of keeping other control variables unchanged, each additional unit of high-speed rail operation will directly increase the regional human capital by 0.164 units, and at the same time, the level of education expenditure will also increase by 0.592 units, resulting in an indirect increase in regional human capital. The increase was 0.0444 units (0.592 × 0.075), and the total effect was 0.2084 (the sum of the direct effect and the mediation effect), of which the mediation effect accounted for 21.3% of the total effect.

From the perspective of labor mobility (mediating variable Z_2), the following findings were revealed: first, from the results presented in columns (4) and (5), we can see that the opening of high-speed rail had a significant positive impact on regional human capital and labor mobility between regions. Second, column (6) shows that, although the influence coefficient (the value was 0.183) of the high-speed rail on regional human capital was significantly positive and passed the significance test at the 1% level, the coefficient of labor mobility was 0.375, which fails the significance test. The Sobel test is required, as shown in Table 9. It can be seen from Table 9 that the Z value of the statistic in the Sobel test was 2.307 (greater than 0.97), and the P value was 0.021 (less than 0.05), indicating that the opening of the high-speed rail, through the positive mediation effect of labor mobility, improved human capital level in the region. The specific analysis shows that the mediation effect of the high-speed rail opening on the human capital in the region through labor mobility was 0.0365, and the total effect was 0.097, of which the mediation effect accounts for 37.6% of the total effect.

Table 9. Sobel test.

	coef	Z	P > |Z|
Sobel	0.0365	2.327	0.01996
Goodman-1 (Aroian)	0.0365	2.307	0.02108
Goodman-2	0.0365	2.348	0.01887
Indirect effect	0.0365	2.327	0.01996
Direct effect	0.0605	0.991	0.3218
Total effect	0.0970	1.550	0.1213
Proportion of total effect that is mediated			0.376
Ratio of indirect to direct effect			0.603
Ratio of total to direct effect			1.603

In conclusion, the opening of high-speed rail can improve the human capital of the region through education investment and labor mobility, verifying the establishment of the two hypotheses (H1 and H2) in this paper. In addition, by further comparing the size of the mediation effect, we found that the mediation effect value of education investment potential (0.0444) was greater than the mediation effect value of labor mobility (0.0365). This shows that the opening of the high-speed rail had a very significant effect on the improvement of regional human capital by promoting the improvement of education investment potential, while the effect of labor mobility was limited.

7. Conclusions and Recommendations

7.1. Conclusions

China's large-scale high-speed rail network construction not only brings opportunities to the improvement of human capital in urban agglomerations, but also induces a potential threat of unequal growth of human capital in urban agglomerations. The aim of this paper was to discern how to promote the flow of talents and optimize the spatial allocation of educational resources through the opening of the high-speed rail to improve the level of human capital in urban agglomerations. In order for the conclusion to be scientific

and reasonable, this paper elaborated the mechanism of the impact of the opening of the high-speed rail on the human capital level of three major urban agglomerations based on the two main lines of labor mobility and education investment potential, and conducted relevant empirical tests. The main conclusions are as follows: (1) the opening of the high-speed rail significantly promoted the overall human capital level of the three major urban agglomerations (20.8%). Among them, the opening of the high-speed rail had the greatest impact on the Beijing–Tianjin–Hebei urban agglomeration, followed by the Pearl River Delta urban agglomeration and the Yangtze River Delta urban agglomeration. (2) The opening of the high-speed rail promotes human capital in the region through the improvement of education investment potential and labor mobility. The mediation effect of education investment potential (0.0444) was greater than that of labor mobility (0.0365). (3) By using "topographic relief" as an instrumental variable to conduct an endogeneity test, randomly generating experimental groups for a placebo test, and selecting "average years of education" to replace the explained variable for a robustness test, the regression results were consistent with the hypothesis, further proving the reliability of the paper's conclusions.

In conclusion, HSR promoted the human capital level of the three major urban agglomerations through labor mobility and educational investment potential, with education investment potential providing a stronger promotion effect, further confirming the fundamental role of education in cultivating human capital; thereby, this paper has significance for the government to take advantage of the high-speed rail, attach importance to the development of local economy, and optimize educational resources.

7.2. Recommendations

The implications of this paper's conclusions are as follows: (1) the local government should make full use of the diffusion effect of central cities, drive the joint development of education in urban agglomerations and urban circles, provide residents with better educational services, and optimize the human capital allocation effect of the high-speed rail. (2) The local government should also encourage multi-level educational and scientific research activities between local-level cities, universities, or scientific research institutions, build a regional scientific research cooperation system, and promote the spatial spillover of knowledge and technology, thereby optimizing the educational investment effect of the opening of the high-speed rail. (3) Furthermore, the government is suggested to pay attention to the development of small- and medium-sized cities in urban agglomerations, give full play to the radiating and leading role of central cities, and promote the coordinated development of regional economies so as to promote the human capital level in urban agglomerations. Due to the incompatibility of the economy and the existence of the high-speed rail siphon effect, some small and medium-sized cities in the Pearl River Delta and Yangtze River Delta urban agglomerations still lag behind in terms overall development level, which makes the development of human capital in the region less optimistic, affecting the overall human capital level of urban agglomerations. Therefore, it is helpful to encourage local governments to give full play to their characteristic resource advantages through policy means, fully realize resource sharing and specialized divisions of labor, and promote local economic development.

Finally, the prospects for future research should be mentioned here. This paper analyzed the impact of high-speed railway construction on the human capital of three major urban agglomerations in China. However, we suggest that further research should be carried out in the following two directions. (1) It would be meaningful to further enrich the sample. At present, there are more than ten urban agglomerations in China. In addition to the three urban agglomerations selected in this paper, the remaining urban agglomerations also have great research value because they contribute to China's economic development. Besides, the sample data of urban agglomerations in the United States, Britain, Japan, and other countries can be added to achieve greater diversification of human capital research. (2) It would be valuable to change the research perspective. Specifically, we can take the urban agglomeration as a unit to study its radiation driving effect on the human capital

level of surrounding small- and medium-sized cities, with the aim of contributing to the coordinated development of the region.

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