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High-speed Rail, Regional Innovation, and Manufacturing Upgrading: Empirical Evidence Based on Prefecture-level Cities in China Title

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Abstract: Eliminating regional differences in economic development is the intrinsic value pursuit of modern governance. Based on the panel data of 285 cities at and above the prefecture level in China, this paper empirically tests the impact of high-speed rail on manufacturing upgrading by using the multi-stage difference-in-difference (DID) model. The result shows that the opening of high-speed railway (referred to as HSR) significantly promotes manufacturing upgrading and regional innovation; the driving effect on manufacturing upgrading in eastern and western cities and large and medium-sized cities is more obvious. The industrial manufacturing chain should be built along with the HSR network, and technological innovation moderates the proposed network. This paper expands the research on the economic effects of HSR opening and provides some guidance for the follow-up construction.

1. Introduction

The outbreak of COVID-19 has made regional differences in the integration of global economic development particularly prominent. Since infrastructure construction plays a role in the regional economic gap [1], it has become an important measure to bridge the coordinated development of the regional economy, especially the high-speed railway construction, which is evident in China’s new development plan. In 2021, China’s economic aggregate was $17 trillion, ranking second in the world, and its per capita GDP ranked 60th in the world. With the rapid development of China’s economy, regional economic development presents an unbalanced situation. The regional economic gap is an important embodiment of unbalanced development in China at present [2]. Including industrial structure remodeling, innovation-driven, and basic investment driving the increase of internal demand, these measures become effective governance to solve the phenomenon of regional imbalance for the government. As the main infrastructure component, the convenience of transportation facilities can effectively reduce the circulating capital of innovation elements among regions, which is conducive to forming a more perfect and developed innovation network [3].

China’s investment in transportation infrastructure has provided important support for economic growth. Since 2004, China’s high-speed rail (HSR) has experienced the planning and layout evolution from “four horizontal and four vertical lines” to “eight horizontal and eight vertical lines”, driving the explosive economic growth in China in the economic transition era. According to the 14th Five-Year Plan (2021-2025) for National Economic and Social Development and Vision 2035 of the People’s Republic of China, the government should develop both traditional and new types of infrastructure in a coordinated way and build a modern infrastructure system that is well-developed, efficient, practical, intelligent, green, safe and reliable, and improve and upgrade infrastructure. By the end of 2021, the total length of China’s high-speed railways in service has exceeded 40,000 km, and the total length of safe operation reached 9.28 billion km, ranking first in the world.

The large-scale construction of high-speed railways accelerates the evolution of urban economic and industrial patterns and leads to a new model of urban development. It fundamentally changes the traditional concept of time and space and constantly reshapes the pattern of China’s economic development. As the core and key content of China’s high-quality economic development, the central government has attached great importance to upgrading the manufacturing industry. It has repeatedly stressed the necessity to continuously promote the transformation and upgrading of the manufacturing industry and build China into a manufacturing power. With its own functional attributes of radiation driving and factor agglomeration, a high-speed railway accelerates the change of spatial allocation of factor resources, amplifies the demographic dividend and resource advantages of cities along the route, improves the level of regional innovation, and plays a great role in boosting the regional manufacturing upgrading. Especially in the context of the COVID-19 epidemic and the intensification of international political and trade frictions, the rise of the high-speed rail network is particularly important for promoting the transformation and upgrading of the manufacturing industry, achieving high-quality economic development, and forming a new development pattern of “internal and external double cycles”. Therefore, it is a real problem to be urgently studied, including an in-depth study of the impact of high-speed rail on the manufacturing industry upgrading and exploring the path and mechanism of such impact.

2. Literature Review

Since the large-scale HSR construction in 2008, the economic effect of HSR has attracted attention from academia. The impacts brought by HSR on economic development, innovation, industry, and the environment are among the main research topics.

2.1. Impacts of HSR on Economic Growth

Academic circles have widely studied the impact of infrastructure on regional economic growth. Based on the studies in the United States [4], Europe [5,6], and India [7], most scholars have reached a relatively consistent opinion that infrastructure plays a significant positive role in regional economic growth [8]. It is widely acknowledged that HSR serves as a boost to economic growth. Chen Mingsheng (2022) and other scholars believed that the government should support infrastructure upgrading and focus on the diffusion effect of the opening of high-speed railways to help narrow the regional economic gap and achieve common prosperity [9]. Chen et al. (2016) conducted a study using the computable general equilibrium (CGE) model and found that HSR significantly stimulated economic growth [10]. Wang and Lu insisted that HSR can bring in a dual economic effect of “pollution reduction” and “quality and efficiency improvement” [11]. However, some scholars argued that HSR did not boost economic growth effectively but instead caused downward pressure on the economy in the marginal areas of HSR stations [12]. In addition, some scholars claimed that infrastructure construction is beneficial to regional economic growth as a whole unit, but this impact may show an obvious inverted "U-shaped" feature [13]. In China, infrastructure as a whole significantly promotes regional economic growth, and there is also an inverted "U" type effect. The output elasticity of network infrastructure has jumped beyond the "inflection point, while the coefficient of point infrastructure is still rising [14]. The "siphon effect" of high-speed rail will widen the regional economic gap [15]. It can be seen that experts have different views on the impact of infrastructure construction on the regional economy, and the research on the relationship between high-speed railways and regional economic development is still not sufficient.

2.2. Impacts of HSR on Industrial Innovation and Upgrading

From the existing relevant literature, new economic geography has confirmed the important role of transportation infrastructure in promoting the flow of innovation factors from a theoretical height [16]. Innovation was affected by HSR mainly from the following aspects: HSR reduced the inter-city mobility cost, accelerated human capital migration and knowledge spillover, enhanced the proportion of highly educated employees in enterprises, and lowered the innovation cost for these enterprises [17], thereby driving the regional technological innovation [18-19]. Bian (2019) argued that HSR was conducive to the interregional flow of innovation elements and would widen the innovation gap between cities along the HSR lines and cities not along the HSR lines [20]. Some studies have explained that based on the construction of transportation infrastructure, the transportation facilities can speed up the inter-regional flow of factor resources and create conditions for industrial upgrading [21]. In other aspects, transportation infrastructure can break the constraints of spatial location on innovation factors and various resources, improve the efficiency of regional economic activities, and expand the flow range of innovation resource factors [22], and the opening of high-speed rail promotes the sharing of knowledge and technology among communities [23]. Innovation can effectively promote the upgrading of industrial structures [24-25].

2.3. Impacts of HSR on the Environment

Transportation infrastructure plays a very important role in regional economic growth, which is recognized by most experts, but its negative impact on the environment has not attracted enough attention from the government [26]. Much research has been conducted concerning the impacts of HSR on the environment. Song et al. [27] measured the environmental efficiency in China using the non-radial data envelopment analysis (DEA) model, with the results suggesting that the railway was the most environmentally friendly means of transport, so it was necessary to make massive investments in HSR construction. In a case study on the Beijing-Shijiazhuang High-speed Rail Line, Chang et al. [28] probed into the impacts of HSR on greenhouse gas emissions and found that HSR remarkably reduced greenhouse gas emissions.

Some scholars thought that the opening of high-speed rail can reduce urban pollutant emissions and improve urban environmental quality, but there was regional and city-level heterogeneity [29]. Strauss et al. [30] found that the unit carbon emission of commercial air travel was 7 times that of high-speed rail. In recent years, the replacement effect of high-speed rail on air travel in China led to an 18% reduction in carbon emission, saving 12 million tons of net carbon emission per year on average. Chen from China f that China's high-speed railway reduced the total energy consumption and energy consumption intensity by promoting industrial agglomeration and technological innovation and has a positive effect on energy conservation and emission reduction [31].

A review of existing works revealed that previous works focused on the impacts of HSR on the whole industrial matrix or a single service sector, but few explored the impacts of HSR on the upgrading of the manufacturing sector and its transmission mechanism. To fill this research gap, the present work made the following innovations. Firstly, a new research perspective was adopted: it studied the influential effect of HSR on manufacturing upgrading by combining HSR with regional innovation and manufacturing upgrading and validated that regional innovation was an important mechanism through which HSR boosted manufacturing upgrading. Secondly, from the perspective of research methods, a time-varying difference-in-difference (DID) model was employed to test the effects of HSR on manufacturing upgrading empirically, the heterogeneity of the impacts of HSR on manufacturing upgrading among different regions were examined, and the mediators were analyzed to identify how HSR affected the manufacturing upgrading.

3. Mechanism Analysis and Research Hypotheses

3.1. Analysis of the Mechanism of How HSR Affects Manufacturing Upgrading

HSR, as a high-density and high-flow capacity transport means, boasts many advantages, including high-speed operation, high on-time performance, large passenger volume, a comfortable ride, and high safety, making it people's first choice for long-distance travel. HSR can expand the scope of regional markets, tap market potential, and significantly foster the large-scale, rapid, and interregional flow of labor force, capital, and other production factors. It can also reduce the searching and matching cost and the transport cost for the demand and supply sides, increase the spatiotemporal allocation efficiency of resources, make more rational and effective use of production factors, and enhance the production capacity and efficiency of the manufacturing industry, thereby making manufacturing upgrading achievable. Besides, HSR can stimulate cities along the HSR lines to carry out a new round of industrial division and collaboration. For instance, to reduce the production cost and distribution cost, a manufacturing enterprise can locate its headquarters and R&D center in a core city and build a headquarters industrial cluster based on this, while its other production processes can be set up in other cities along the HSR lines to form an agglomeration of manufacturing production factors. This practice helps boost industrial division and collaboration, as well as the optimization and upgrading of the industrial structure. From the perspective of the HSR manufacturing industry itself, as a typical representative of high-end manufacturing, the upgrading of its R&D technologies and production processes will produce an anti-driving effect on relevant upstream and downstream industries, thereby driving the transformation and upgrading of other manufacturing industries and ultimately promoting the upgrading of the entire manufacturing industry. Thus, the following hypothesis is proposed:

Hypothesis 1: HSR promotes manufacturing upgrading by improving the spatiotemporal allocation efficiency of resources and boosting industrial division and collaboration.

3.2. Analysis of the Mechanism of How HSR Affects Regional Innovation

The impacts of HSR on regional innovation are as follows. Firstly, HSR produced a "knowledge spillover effect". The formation of the HSR network has shortened the spatiotemporal distance of knowledge and technology diffusion, accelerated the integrated development of the regional economy, and created convenient conditions for the spillover of knowledge, technology, and other innovation elements. By boosting exchanges and cooperation in knowledge, technology, and talent through the HSR network, relevant industries, universities, research institutions, and governments in cities along the HSR lines can foster the agglomeration of innovation resources and the implementation of innovation activities [32]. Reduced commuting cost brought by HSR is an important reason why communication and contact among enterprises in different places are increased. In addition to enhancing the synergistic innovation level of enterprises, this will help latecomers learn the knowledge and management experience of advanced enterprises and thereby improve their innovation efficiency. The "spatiotemporal compression" and "boundary breakthrough" effects of the HSR network can effectively reduce unnecessary losses incurred in technology spillover and lessen leakage and content distortion of technology during diffusion and transmission. Secondly, HSR can produce a "human capital allocation and promotion effect" that can effectively promote the human capital flow and agglomeration in cities, remarkably enhance the local human capital level, and offer the necessary support for the improvement of regional innovation capacity and innovation efficiency. Thereby, the following hypothesis is proposed:

This paper put forward the following research hypothesis based on the above analysis.

Hypothesis 2: HSR enhances regional innovation by creating a "knowledge spillover effect" and a "human capital allocation and promotion effect".

3.3. Analysis of the Mechanism of How HSR Affects Manufacturing Upgrading through Regional Innovation

Innovation is a very important channel through which HSR affects manufacturing upgrading. The accelerated diffusion of information, technology, and knowledge triggered by HSR can promote the structural upgrading of the whole industrial chain. Especially for the manufacturing industry, relying on high-level scientific research and development, massive investments in HSR construction will expand the scale and radiation scope of market demand, facilitate the formation of the scale economy effect, the factor recombination effect, and the knowledge spillover effect, which can further improve the pace of technology spillover and the potential for independent innovation capacity and push forward manufacturing upgrading. From the microscopic perspective, HSR produced the following benefits, including breaking through the spatiotemporal constraints between investors and enterprises, expanding the boundaries of cities, reshaping the regional time pattern, greatly reducing the travel cost and time cost between the two sides, improving the speed and quality of information communication and interaction, allowing technology and innovation knowledge and other innovation elements to overflow in a larger space, and boosting innovation inputs and outputs. Furthermore, HSR strengthened interregional collaboration and connected regions more closely from a macro perspective. Because of this, the rational optimization and allocation of factor resources were achieved, the sharing and interaction of factor resources were increased, and the regional innovation efficiency and level were thus improved. Consequently, the improvement in urban accessibility brought about by HSR, to a certain extent, drove the flow of innovation elements, optimized the regional innovation pattern, and promoted manufacturing upgrading. Thus, the following research hypothesis is proposed:

Hypothesis 3: Regional innovation is an important mechanism for HSR to promote manufacturing upgrading.

4. Measurement Model and Data Description

4.1. Construction of the Measurement Model

Due to the impact of multiple factors such as regional policies, economic development, and geographical positions, the HSR line planning and station selection serve specific purposes. Therefore, HSR is not the result of the impact of purely exogenous policies. Besides, problems arising from endogenous growth should be taken into account when analyzing the impacts of HSR on manufacturing upgrading. To test the impacts of HSR on manufacturing upgrading, samples in the present work were divided into two groups, i.e., the experimental group consisting of cities with HSR and the control group consisting of cities without HSR. A time-varying model was also constructed:

$$Manufacture_{it} = \alpha_0 + \beta_0 HSR_{it} + \theta_0 Control_{it} + \mu_i + \lambda_t + \varepsilon_{it} \quad (1)$$

where, i and t represent the region and the year, respectively. $Manufacture_{it}$ is the explained variable representing manufacturing upgrading; HSR_{it} is the core explanatory variable representing the virtual variable of HSR; $Control_{it}$ represents other control variables that might affect manufacturing upgrading; u_i and λ_t represent the urban fixed effect and time fixed effect; ε_{it} represents the random error term.

According to the test steps, firstly, based on equation (1), the influence of high-speed railway on regional innovation was tested; Secondly, equation (2) was established, and regional innovation was set as the explained variable, and the existence of mediating effect was tested by examining the influence of high-speed railway on regional innovation. Thirdly, the opening of the high-speed railway and the mediating variables were taken as explanatory variables, and equation (3) was established to test whether the mechanism of action was effective.

Then, manufacturing upgrading was represented as a function of the improved regional innovation level brought by HSR:

$$INV_{it} = \alpha_1 + \beta_1 HSR + \theta_1 Control_{it} + \mu_i + \lambda_t + \varepsilon_{it} \quad (2)$$

$$Manufacture_{it} = \alpha_2 + \beta_2 HSR_{it} + \delta INV_{it} + \theta_2 Control_{it} + \mu_i + \lambda_t + \varepsilon_{it} \quad (3)$$

where represents the regional innovation level.

4.2. Indicator Selection and Data Description

Explained variable: manufacturing upgrading. No consensus has been reached on the measurement of the manufacturing upgrading indicator, but the quantitative expression of manufacturing climbing the value chain in existing studies is largely about upgrading output capacity, that is, the improvement of production efficiency and earnings-generating capacity. Based on data availability and the method, we selected the total profits and taxes of the manufacturing industry to reflect the manufacturing upgrading level. Total profits and taxes (the sum of total profits and main business taxes and surcharges of industrial enterprises) are used to measure the profitability of the manufacturing industry.

Core explanatory variable: HSR. The primary basis for the definition of HSR in this paper is that a city owns HSR stations. Where a city has multiple HSR lines, the year when the earliest HSR line was opened in the city shall prevail. The earliest opening time of HSR, as defined in this paper, was from the Hening Section of the Ningrong Railway, the Qingdao-Jinan Passenger Railway, and the Beijing-Tianjin Intercity Railway in 2008. Due to the time lag in the effect of putting HSR into operation, this paper drew on the practice of the previous study. If an HSR line was opened before June, the virtual variable of HSR in the current year was 1; if an HSR line was opened between July and December, the virtual variable of HSR was 1 in the year following the opening of the HSR line and was 0 in the current year. Due to data availability, a total of 285 cities at and above the prefecture level were included in our analysis. The year 2016 is the most recent year for which the data of these cities are available, so 2016 was taken as the time boundary. Cities, where HSR lines were opened before 2016 served as the experimental group, and cities where HSR lines were not opened as of 2016 served as the control group.

Regional innovation. The urban innovation index (2004-2016) measured in the Report on *China's Urban and Industrial Innovation* was used as the measurement indicator for the regional innovation level. This index was obtained by estimating the patent value through the patent renewal model and adding it up to the city level.

Table 1: Definition and statistical description of variables

Name of variable	Symbol of variable	Calculation method	Average	Minimum value	Maximum value
Total profits and taxes	*Manufacture*	The logarithm of the sum of total profits and main business taxes and surcharges of an industrial enterprise	13.582	5.628	17.776
HSR	*HSR*	With HSR = 1; Without HSR = 0	0.193	0	1
Regional innovation	*INV*	Refer to Kou et al. (2017)	7.443	0.005	1061.37
Economic development level	*PGDP*	Logarithm of the per capita GDP	10.142	4.595	13.056
Human capital level	*HU*	Proportion of college students in total population	0.016	1.00e-05	0.131
Degree of opening-up	*OPEN*	Proportion of actual utilization of foreign capital in regional GDP	0.02	0.00001	0.182
Infrastructure level	*INFRA*	The logarithm of pavement road area per capita	2.177	-3.912	4.686

Control variables: some other variables that might affect manufacturing upgrading were also controlled in the present work. Based on existing studies, the following variables were selected: economic development level ($PGDP$), which is measured by the per capita gross domestic product; human capital level (HU), which is measured by the proportion of college students in the total population; the degree of opening-up ($OPEN$), which is measured by the proportion of actual utilization of foreign capital in regional GDP; infrastructure level ($INFRA$), which is measured by the pavement road area per capita.

The data for the present work is from the *China City Statistical Yearbook*, *China Statistical Yearbook for Regional Economy*, *China City Yearbook*, and the statistical yearbooks of provinces and cities from 2005 to 2017. Given the missing statistical data or administrative division adjustments in some cities, 285 cities at and above the prefecture level were finally determined as the samples. The reason why citywide data rather than municipal-district-level data were used in this paper is that in most of the prefecture-level cities with HSR, the stations are often built far away from the downtown areas. Besides, the local government hopes to take advantage of the opportunities brought by HSR to accelerate the building of new HSR cities, create a new engine for economic development, and drive the high-quality development of the whole region. As such, the impacts of HSR on manufacturing upgrading can be assessed more accurately and scientifically by selecting citywide data rather than municipal-district-level data. (Table 1)

5. Empirical Results and Analysis

5.1. Analysis of Benchmark Regression Results

The time-varying (DID) model was employed to analyze the impacts of HSR on manufacturing upgrading. As Table 2 shows, in Column (1), the impact coefficient of HSR on manufacturing upgrading was 1.349, which passed the 1% significance test. To test the robustness of the regression coefficient, we introduced a series of control variables on the basis of Column (1) and obtained the estimation results in Columns (2)-(5).

The estimation results showed that after the economic development level, human capital level, degree of opening-up, infrastructure level, and other factors were controlled, the symbol and significance of the explained variable did not change, indicative of good robustness for the estimation results. The following conclusion can thus be drawn from this: HSR had a significant promoting effect on manufacturing upgrading, which, in turn, supported that Hypothesis H1 was established. Other control variables were also basically in line with the expectations. The economic development level, human capital level, degree of opening-up, and infrastructure level all had a positive effect on manufacturing upgrading.

Table 2: Benchmark regression results of the impacts of HSR on manufacturing upgrading

Variable	(1)	(2)	(3)	(4)	(5)
HSR	1.349*** (0.057)	0.25*** (0.053)	0.229*** (0.052)	0.249*** (0.051)	0.247*** (0.051)
PGDP		1.274*** (0.029)	1.246*** (0 .032)	1.221*** (0.032)	1.134*** (0.038)
Hu			2.532** (1.018)	1.089 (1.039)	1.075 (1.038)
OPEN				5.709*** (0.995)	5.082*** (1.011)
INFRA					0.185*** (0.037)
C	13.321*** (0.026)	0.608** (0.289)	0.857*** (0.3145)	1.02*** (0.315)	1.51*** (0.336)
Fixed effect	Yes	Yes	Yes	Yes	Yes
N	3705	3705	3705	3705	3705
R^2	0.127	0.495	0.496	0.502	0.505

Note: The robust standard deviation is shown in parentheses. "*", "**" and "***" indicate the value is significant at the statistical levels of 10%, 5%, and 1%, respectively.

5.2. Robustness Test

5.2.1. Parallel Trend Test

Table 3: Parallel trend test

Variable	*Manufacture*	Variable	*Manufacture*
Before6	-0.039 (0.093)	*After1*	0.137** (0.056)
Before5	-0.061 (0.083)	*After2*	0.093 (0.086)
Before4	-0.043 (0.076)	*After3*	0.177* (0.104)
Before3	-0.1 (0.081)	*After4*	0.209** (0.102)
Before2	0.031 (0.072)	*After5*	0.226** (0.094)
Before1	0.036 (0.045)	-	-
Fixed effect	Yes	Fixed effect	Yes
N	3705	*N*	3705
R^2	0.577	R^2	0.577

Note: The robust standard deviation is shown in parentheses. "*", "**" and "***" indicate the value is significant at the statistical levels of 10%, 5%, and 1%, respectively.

It should be noted that the parallel trend hypothesis test is an essential testing step in modeling. As a result, a further test was performed on whether the experimental group and the control group met the common trend hypothesis before the implementation of policies. As Table 3 shows, the estimation results passed the parallel trend test, indicating the time-varying model was effective for estimation in this paper. Moreover, within five years after the implementation of the policies, their marginal impacts largely showed a rising trend year by year.

5.2.2. Analysis of Heterogeneous Impacts

Table 4: Regression results of different regions and city sizes

Variable	(1)	(2)	(3)	(4)	(5)	(6)
	Eastern cities	Central cites	Western cities	Large cities	Medium cities	Small cities
HSR	0.16** (0.073)	0.125 (0.078)	0.058*** (0 .161)	0.301*** (0 .055)	0.242*** (0.092)	0.294 (0.191)
PGDP	1.253*** (0.052)	1.066*** (0.058)	1.157*** (0.085)	1.286*** (0.036)	0 .866*** (0.076)	1.221*** (0.082)
Hu	-2.082 (1.552)	-0.534 (2.463)	8.99*** (1.509)	3.286*** (0.982)	32.444*** (4.319)	31.529*** (11.265)
OPEN	1.519 (1.3)	-0.883 (1.73)	9.931*** (3.019)	1.491* (0.837)	-1.156 (2.377)	10.427*** (2.985)
INFRA	0.494*** (0.055)	0.152** (0.065)	-0.228*** (0.0715)	0.242*** (0 .037)	0 .567*** (0 .092)	-0.15 (0.106)
C	-0.195*** (0.479)	2.574*** (0.521)	1.703** (0.728)	0 .411*** (0.323)	3.535*** (0.666)	0.79*** (0.676)
Fixed effect	Yes	Yes	Yes	Yes	Yes	Yes
N	1573	1040	1092	2015	1157	533
R^2	0.526	0.427	0.467	0.638	0.386	0.442

Note: The robust standard deviation is shown in parentheses. "*", "**" and "***" indicate the value is significant at the statistical levels of 10%, 5% and 1%, respectively.

The samples in the present work were further divided into six categories, including eastern cities, central cities, western cities, large cities (with a population of more than 1 million in the municipal district), medium cities (with a population of 0.5-1 million in the municipal district) and small cities (with a population of less than 0.5 million in the municipal district), to separately explore the heterogeneity in the impacts of HSR on the manufacturing upgrading in different regions and cities of different sizes. The respective regression results of eastern, central, and western cities are shown in Columns (1), (2), and (3) of Table 4 and indicate that HSR had a promoting effect on manufacturing upgrading. In particular, HSR had a greater impact on the manufacturing industry in eastern and western cities. This is because there are abundant factor resources such as labor force, capital, and technology in the eastern region, and HSR accelerated the optimization and allocation of various factor resources and promoted manufacturing upgrading. While in the western region, the traffic infrastructure level has been low for a long time, the traffic condition is backward, and the regional liquidity is weak. HSR would further shorten the spatiotemporal distance between western and eastern cities, speed up the integration of factor resources, and exert a significant promoting effect on manufacturing upgrading. The regression results of the large, medium, and small cities are shown in Columns (4), (5), and (6). HSR had a positive effect on the manufacturing upgrading either in large, medium, or small cities and had more obvious impacts on large and medium cities. This is because the population size can reflect the economic development level of a city to a certain extent. A city with a larger population size often has a higher economic development level and has a congenital advantage in talent introduction and capital accumulation. In particular, HSR enabled factor resources to flow more conveniently among regions and thereby promoted manufacturing upgrading.

5.2.3. Propensity Score Matching-Differences-in-Differences (PSM-DID)

Table 5: PSM-DID robustness test

Variable		Average		Standard error (%)	Error reduction (%)	*t* -test		Estimation results
		Experimental group	Control group			*t*	*p*	
PGDP	Before matching	10.837	9.975	132.6	-	28.97	0.00	1.045***
	After matching	10.82	10.831	-1.7	98.7	-0.38	0.71	(0.038)
HU	Before matching	0.03	0.012	68.4	-	20.38	0.00	0.813
	After matching	0.028	0.025	12.0	82.5	1.98	0.48	(1.067)
OPEN	Before matching	0.024	0.019	24.3	-	5.57	0.00	6.529***
	After matching	0.024	0.022	10.2	58.1	1.93	0.53	(0.928)
INFRA	Before matching	2.526	2.093	75.4	-	17.00	0.00	0.192
	After matching	2.517	2.577	-10.4	86.2	-2.13	0.33	(0.039)
HSR	-	-	-	-	-	-	-	0.27*** (0.051)

Note: The robust standard deviation is shown in parentheses. "*", "**" and "***" indicate the value is significant at the statistical levels of 10%, 5%, and 1%, respectively.

Since the HSR line planning and station site selection are inevitably affected by the geographical position, economic development level, and administrative level of cities and have specific purposes, HSR is not the result of the impact of purely exogenous policies (Wang et al., 2020). This might also lead to errors in the selection of samples, resulting in the imprecision of the estimation results. Therefore, this paper adopted the PSM-DID method to test the impacts of HSR on manufacturing upgrading for robustness again. PSM was used to match the scores of cities with the same characteristics, and the matched characteristic variables were the control variables of this paper, including the economic development level, human capital level, degree of opening-up, and infrastructure level, and with or without HSR served as the explained variable. After PSM, a parallel trend test was performed on the matched samples. The test results in Table 5 indicate that HSR had a significant promoting effect on manufacturing upgrading, and there was no difference with the above analysis results, which further supported the previous research conclusions.

5.3. Mechanism Test

After the robustness test of the empirical results, we believed that the positive impacts of HSR on manufacturing upgrading were robust. Then, how did HSR affect manufacturing upgrading? Or is regional innovation an important mechanism through which HSR affects manufacturing upgrading? To answer this question, this paper used the mediating effect model to further test the mechanism of how HSR affected manufacturing upgrading on the basis of the above theoretical analysis. The results in Table 6 show that both the impact coefficient of HSR on the regional innovation level and the impact coefficient of the regional innovation level on manufacturing upgrading were significantly positive. Hence, we can say that HSR promoted manufacturing upgrading by boosting regional innovation, thereby supporting hypotheses H2 and H3. This is large because HSR fostered human capital flow, facilitated knowledge transmission and diffusion, and boosted the regional innovation level, which, in turn, would promote manufacturing upgrading.

Table 6: Mechanism test

Variable	*INV*	*INV*	*Manufacture*	*Manufacture*
	(1)	(2)	(3)	(4)
HSR	27.807*** (3.224)	17.112*** (2.33)	1.131*** (0.061)	0.185*** (0.051)
INV			0.008*** (0.001)	0.004*** (0.0007)
PGDP		9.724*** (1.69)		1.099*** (0.038)
Hu		258.656*** (31.244)		0.145 (1.049)
OPEN		53.896*** (19.411)		4.898*** (1.002)
INFRA		-5.742*** (1.785)		0.206*** (0.037)
C	2.069*** (0.155)	-87.127*** (14.4)	13.305*** (0.026)	1.82*** (0.336)
Fixed effect	Yes	Yes	Yes	Yes
N	3705	3705	3705	3705
R^2	0.075	0.128	0.168	0.513

Note: The robust standard deviation is shown in parentheses. "*", "**" and "***" indicate the value is significant at the statistical levels of 10%, 5%, and 1%, respectively.

6. Research Conclusions

The impacts of HSR on manufacturing upgrading and its mechanism were empirically tested using the panel data of 285 cities at and above the prefecture level from 2004 to 2016 and adopting the time-varying DID model. The research results are as follows: firstly, HSR promoted manufacturing upgrading on the whole, and this conclusion still held true after a robustness test; secondly, there was heterogeneity in the impacts of HSR on manufacturing upgrading among different regions, and specifically, HSR had a more pronounced promoting effect on cities in eastern and western China and large and medium cities; thirdly, a further mediating effect test suggested that regional innovation was an important transmission channel for HSR to affect manufacturing upgrading and the improved regional innovation level brought by HSR was conducive to manufacturing upgrading.

7. Policy Suggestions

With the annual opening and acceleration of high-speed railway construction in various parts of China, it is bound to form a strong external impact situation, and its influence on the optimization and adjustment of regional industrial structure should be diversified and complex, especially in the context of the current economic transformation and high-quality development strategy, which will be more prominent. Therefore, the following policy-making suggestions were proposed according to the research conclusions:

Firstly, governments should give scientific guidance to strengthen the positive effects of HSR on manufacturing upgrading, and play the moderating role of innovation in China atnational and regional levels. Based on their endowments and conditions, the governments along the HSR lines should seize the development opportunities, do rational planning for the industrial spatial layout and development pattern, expand the market radiation scope and demand scale, and regulate and guide the positive effects of HSR on the local manufacturing development, facilitate the optimized resource allocation and industrial division pattern of cities, and boost the transformation and upgrading of urban manufacturing.

Secondly, the construction of the HSR network should be improved to further enhance the spatial allocation efficiency of resources. Consequently, the construction of the HSR network should be accelerated and improved by closely following the "14th Five-year Plan" and the "Traffic Power" development strategy. The eastern region should continue to optimize the HSR line and station planning. The central and western regions should take enhancing the radiation and driving functions of core cities as a primary task and give priority to making planning and arrangements for the construction of HSR lines in key urban agglomerations and metropolitan circles.

Thirdly, the optimization of the regional industrial layout should be accelerated with the help of the "spatiotemporal compression" effect of HSR. The industrial manufacturing chain should be built along with the HSR network, and the coordinated development of various departments in the industrial chain should be promoted to form complementary advantages. Besides, great efforts should be made to develop producer services matching the transformation and upgrading of the manufacturing industry, such as finance, commerce and trade, smart logistics, and scientific technologies. On this basis, advanced manufacturing should be cultivated, developed, and built into a new growth point to drive the transformation and upgrading of urban manufacturing.

Fourthly, inputs should be made into actively optimizing and enhancing the mediating effect of regional innovation and giving full play to the innovation effect of HSR. The allocation effect of the market mechanism on innovation resources should be strengthened to create a sound market environment and legal environment for scientific research and development activities and speed up the free flow of information, knowledge, technology, and other innovation elements.

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Data Availability

The data that support the findings of this study are openly available in public resources. The index data of regional innovation level is derived from the urban innovation index (2004-2016) measured in "China's Urban and Industrial Innovation Capacity Report". Other data used in the text are from 2005 to 2017 China City Statistical Yearbook, China Regional Economic Statistical Yearbook, China Statistical Yearbook, and statistical yearbooks of provinces and cities. All the above data can be searched and downloaded from the official website. This paper guarantees that the data used in the text are true and effective.

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