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The Opening of High-Speed Rail and Economic Growth: The Moderating Role of Government Efficiency and Innovation Environment

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Abstract: This paper selects the panel data of 297 cities in China from 2003 to 2017 and analyzes the effects of government efficiency and innovation environment on the relationship between high-speed rail opening and economic growth from the perspective of government competition pressure and information flow by using the approach of difference-in-differences (DID). The findings are as follows: first, the opening of high-speed rail has a significant promoting effect on regional economic growth; second, government efficiency has negative impact on the relationship between high-speed rail development and economic growth, while the innovation environment has positive impact on this relationship; third, the moderating effects of government efficiency and innovation environment exhibit regional heterogeneity. This paper provides a new perspective from the perspectives of government competition pressure and information flow for understanding the impact of high-speed rail on the economy, offering insights for promoting the coordinated and sustainable development of the Chinese economy.

Keywords: government efficiency; innovation environment; transport infrastructure; economic growth; high-speed railway

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1. Introduction

The construction and improvement of transportation infrastructure can reduce the production and transportation costs of products, promote the rapid flow of information and resources, enhance resource allocation efficiency, and increase the level of market integration. It is a new engine for regional economic growth and development [1]. In recent years, China's high-speed rail construction has made significant progress, from the opening of the first true high-speed rail, the Beijing-Tianjin intercity high-speed rail in 2008, to becoming the country with the largest high-speed rail network in the world in just over a decade. By the end of 2020, the operating mileage of China's high-speed rail reached 37,900 km, nearly doubling during the "Thirteenth Five-Year Plan" period, firmly ranking first in the world. With the improvement of China's "Eight Vertical and Eight Horizontal" high-speed rail network, China National Railway Group proposed the development goals for the first stage of China's high-speed rail in the new era in the "Outline of the Railway Leading Plan for Building a Transportation Power in the New Era", released on 13 August 2020. The goal is to achieve a national high-speed rail network operating mileage of 70,000 km by 2035, with high-speed rail accessibility to cities with a population of over 500,000, the construction of smart high-speed rail leading the way, and the formation of a comprehensive national 1, 2, and 3-h high-speed rail travel circle. The rapid and comprehensive development of high-speed rail can significantly shorten the distance in time and space, improve the accessibility between regions, and is particularly crucial for regional economic growth.

At a macro level, the opening of high-speed rail is crucial for regional economic growth. Current research on the question of "how the opening of high-speed rail affects economic growth" presents two main viewpoints. One perspective argues that the opening of high-speed rail can stimulate regional economic growth by increasing capital investment, promoting population migration, enhancing overall factor productivity, and generating urban agglomeration effects [2]. On the other hand, another viewpoint suggests that while high-speed rail accelerates the flow of production factors, it may also lead to the concentration of resources such as funds, talents, and information in more developed cities. This, in turn, could result in less favorable investment environments or the phenomenon of resource outflow, particularly in cities facing congestion effects. This situation may exacerbate the disparities between regions with and without high-speed rail, hampering the coordinated development of regional economies [3–5]. Given this, the first question this paper focuses on is whether the opening of high-speed rail can significantly promote regional economic growth.

The opening of high-speed rail facilitates communication and exchange between governments in different cities and regions, leading to faster information flow and increased transparency. The rapid flow of information reduces the difficulty of comparing governments, making differences in efficiency more apparent [6]. For governments with lower efficiency, this transparency of differences increases perceived competitive pressure, compelling them to take action to promote efficiency improvement, thereby influencing the "net effect" of high-speed rail on economic growth. For different cities and regions, variations in the innovation environment can result in differences in the speed of flow of innovative elements and information brought about by the opening of high-speed rail, thus affecting the extent of its impact on economic growth [7]. However, existing research has mostly explored the impact of high-speed rail on the macroeconomy from a single perspective, without exploring the contextual conditions of how the efficiency of government and the innovation environment influence the economic growth effects of high-speed rail opening. Therefore, the second question this paper focuses on is how government efficiency and the innovation environment affect the economic growth impact of the opening of high-speed rail.

The "14th Five-Year Plan" outline emphasizes the development and growth of urban clusters and metropolitan areas, promoting the integrated development of urban clusters and forming a comprehensive "two horizontal and three vertical" urbanization strategic pattern. The emergence and development of urban clusters reflect the high concentration of economic activities within them in the context of globalization. Within urban clusters, different cities can leverage their respective advantages, further enhancing agglomeration effects and positive spatial externalities, ultimately boosting the overall economic development of urban clusters. Based on the approved and pending approval lists of urban clusters, this paper classifies cities in China into three types: central cities of urban clusters, peripheral cities of urban clusters, and cities outside urban clusters. Different types of cities exhibit significant differences in infrastructure construction, government efficiency, innovation environment, and economic development. These differences may result in varying degrees of resource agglomeration and information flow brought about by the opening of high-speed rail, leading to differences in the impact of government efficiency and the innovation environment on the relationship between high-speed rail opening and economic growth in different cities. Therefore, the third question this paper focuses on is whether there is regional heterogeneity in the moderating effect of government efficiency and the innovation environment on the relationship between high-speed rail opening and economic growth across different types of cities.

This article focuses on China's prefecture-level cities, utilizing a multi-period difference-in-differences method to delve into the impact of high-speed rail (HSR) opening on economic growth. Furthermore, it conducts an in-depth analysis of the moderating role of government efficiency and innovation environment in the relationship between HSR opening and economic growth. In comparison to existing research, potential innovations in this

article are primarily reflected in several aspects. First, there is no consensus in existing research regarding whether the opening of HSR significantly promotes economic growth. Therefore, clarifying how HSR opening influences economic growth is helpful in elucidating the current academic understanding of this ambiguous impact. Second, previous studies have only explored the direct impact of HSR opening on government efficiency and the innovation environment. However, for cities and regions with different government efficiency and innovation environments, the impact of HSR opening on economic growth may vary significantly. Thus, this article, from the perspective of government competition pressure and information flow, incorporates government efficiency and the innovation environment into the theoretical model of the impact of HSR opening on economic growth, further exploring how government efficiency and the innovation environment influence the relationship between HSR opening and economic growth. Third, this paper then analyzes whether there is regional heterogeneity in the moderating effect of government efficiency and the innovation environment on the relationship between HSR opening and economic growth among different types of cities. Lastly, this article adopts a multi-period DID method, using the year of HSR opening in each city as the policy implementation node. This approach allows for a more accurate assessment of the net effects brought about by HSR opening. Various methods, such as parallel trend tests, dynamic tests, instrumental variable methods, and variable substitution, are employed to examine the feasibility of the research methodology and the robustness of the research results.

2. Literature Review

Compared to traditional modes of transportation, the inherent features of HSR such as high passenger capacity, speed, punctuality, and safety contribute to reducing the costs of talent and knowledge mobility. HSR plays a crucial role as a link in communication between cities [8]. From a macro perspective, existing research has focused on the impact of HSR opening on various aspects of urban economic development [9], innovation capabilities [10], and information flow [7]. It is believed that HSR serves as a significant driving force for regional industrial agglomeration and diffusion, facilitating the diffusion and transfer of innovation elements between regions and improving the efficiency of information transmission [5]. On a micro level, research related to HSR primarily concentrates on its impact on enterprise innovation [11], capital flow [1], enterprise resource allocation [12], and enterprise productivity [13]. It is argued that the opening of HSR shortens business travel time, accelerates the flow of factors such as funds and technology, reduces information asymmetry, and consequently promotes the enhancement of corporate competitiveness.

The theory of the big push asserts that the development of infrastructure, such as transportation [14], is a crucial prerequisite for driving a country's economic development and social progress. The development of transportation infrastructure, including the opening of HSR, is closely related to economic growth [15]. Scholars have studied the relationship between transportation infrastructure development and economic growth from various theoretical perspectives. However, there is currently no consensus on the impact of HSR opening on economic growth. One viewpoint suggests that the opening of HSR can significantly promote urban economic growth by reducing transaction costs, enhancing regional accessibility, and stimulating employment [2,16]. However, another perspective argues that HSR may increase the accessibility of the opened region, thereby widening the economic gap between the opened and unopened regions [4,17]. Additionally, the impact of HSR on economic growth depends on factors such as regional network layout, construction costs, and environmental costs. Moreover, HSR construction is characterized by a long construction period, significant upfront investment, and high operating maintenance costs, making its immediate impact on economic growth less pronounced [3,18]. According to the new economic geography, the gradual improvement and development of the HSR network not only drives regional economic growth but also leads to the transfer of various economic factors between regions, resulting in significant changes in the spatial distribution pattern of regional economies. The economic consequences of HSR can be summarized as

the "urban effect", "corridor effect", and "siphon effect" [19]. Based on this analysis, an in-depth study on whether the opening of HSR can significantly promote the economic growth of Chinese cities holds great theoretical and practical significance.

New Structural Economics posits that proactive government and effective markets are essential conditions for rapid economic development. While the opening of HSR can enhance a city's locational advantage and improve its capacity to attract resources, the key to ensuring the full allocation and application of resources and advantages lies in government and market efficiency [19]. Government efficiency is a significant manifestation of the governance level of a government. According to the World Bank's definition of the "Worldwide Governance Indicators", the ultimate goal of improving government efficiency is to promote social equity and economic development [20]. The level of government efficiency largely depends on the environment in which a region is situated, especially the "hard environment" such as transportation infrastructure. Existing research has mostly focused on how internal mechanisms of government (such as governance tools and methods) influence government efficiency, neglecting the impact of external mechanisms (such as transportation infrastructure). As a convenient means of transportation, HSR, on one hand, creates a time-space compression effect, promoting rapid capital aggregation and efficient resource allocation [21]. On the other hand, it facilitates the disclosure of government information, enabling quick and accurate decision-making, thus influencing government efficiency [6].

The innovation environment encompasses various aspects such as innovative infrastructure, market environment, financial environment, and workforce quality. It reflects whether a region has abundant human capital and financial resources [22]. According to endogenous growth theory, the improvement of the urban innovation environment and the enhancement of innovation capabilities depend primarily on R&D investment and knowledge spillover [23]. Among these, R&D talent and R&D funding are crucial for the introduction and development of high-tech industries, serving as important indicators of measuring R&D investment. Existing research, based on the perspective of "innovation factor flow", explores the impact of HSR opening on the innovation environment from three aspects: talent, funds, and information. First, HSR opening can improve infrastructure construction, enhance transportation convenience, and accelerate the speed of talent flow between regions, facilitating the aggregation of innovative talent within the region [24]. Second, HSR opening can reshape the spatial structure of cities, improve resource allocation efficiency, create investment opportunities within the city, increase venture capital, and reduce innovation costs [21]. Finally, HSR opening can accelerate the speed of information flow, enhance the accessibility of knowledge, and promote the transfer and diffusion of knowledge and technology between regions, providing crucial support for the conduct of innovation activities [25,26]. Moreover, HSR opening can drive the innovation development of high-tech industries (such as science and technology, finance, and information) in cities along the rail line and the surrounding areas, providing necessary support and guarantees for optimizing the urban innovation environment [27]. In conclusion, when exploring the impact of HSR opening on economic growth, the introduction of government efficiency and innovation environment is essential.

3. Theoretical Analysis and Research Hypothesis

3.1. The Opening of High-Speed Rail and Economic Growth

The construction and development of transportation infrastructure has a significant impact on economic growth [28,29]. Rostow [30] proposed, in the stages of economic growth theory, that developing countries should prioritize the development of transportation infrastructure. High-speed rail, as an investment project in transportation infrastructure aimed at boosting the economy and promoting development, has become a crucial force driving overall economic growth in China [2].

The opening of HSR significantly enhances regional economic growth. On one hand, HSR alleviates the temporal and spatial constraints resulting from geographical distances,

improving accessibility between regions and affecting the concentration of factor rents [31]. It accelerates the cross-regional flow of resources such as information and labor, reducing the costs associated with acquiring, creating, and transferring knowledge for cities. Moreover, it facilitates population migration between regions, stimulates the development of service industries like tourism, catering, and real estate, increases employment opportunities in cities along the route, and enhances their market consumption capacity, ultimately promoting economic growth [32]. The capital investment required for HSR construction and the development of high-tech industries resulting from HSR opening also directly stimulate economic growth. Additionally, HSR opening accelerates the gathering and transmission of talents, knowledge, and production factors, generating urban agglomeration effects and laying a solid foundation for economic growth in terms of knowledge and human capital [33].

On the other hand, from the perspective of information flow, China's vast territory and large population introduce various "noises" that impact information transmission between cities. Studies suggest that in regions with convenient transportation, the negative impact of geographical distance on information transmission is relatively weak [34]. The opening of HSR compresses time and space, improves accessibility, reduces information asymmetry, enhances the quality and efficiency of information transmission, and promotes synergistic economic development. From the standpoint of micro-level entities such as enterprises, HSR opening strengthens close communication between businesses, lowers information communication costs, optimizes resource allocation efficiency, and raises overall factor productivity, thereby fostering urban economic growth [34]. Some research, however, suggests that the "siphoning effect" generated by HSR opening may lead to a "reverse flow" of factors and resources in underdeveloped areas along the HSR line, hindering economic growth in these regions [35,36]. In the long term, HSR opening can drive industrial development in the surrounding regions. Coupled with the advantages of "time-space compression" and "information transmission", it can offset the potential adverse effects of resource "reverse flow" and significantly promote local economic development. Therefore, the following hypothesis is proposed:

H1. *The opening of HSR can significantly boost the regional economic growth.*

3.2. The Moderating Role of Government Efficiency

China is vigorously promoting the transformation of government functions from a managerial government to a service-oriented government, and local governments play a crucial role in regional economic growth and development. The efficiency of local governments has long been a focus of academic attention, providing an important perspective for analyzing regional economic phenomena [37]. Government efficiency is a significant reflection of the local government's administrative service level [38] and transaction costs, exerting a notable impact on the economic behavior types of a city [39]. By strengthening government service construction, improving the quality of tax services, and enhancing government-business relationships, efficiency can be enhanced, reducing ineffective interventions and lowering institutional transaction costs [38]. The geographical distance between different cities can affect the quality and speed of information transmission between governments. Moreover, local governments, driven by various self-interest reasons, such as concealing ineffective policy implementation, may reduce the disclosure of crucial information. When the cost of acquiring information related to government decision-making is high, it can adversely affect the improvement of government efficiency [6].

Existing research, based on signaling theory, has explored the direct impact of HSR opening on government efficiency. It suggests that HSR opening can generate a "time-space compression" effect, increasing the frequency of scrutiny and research by policymakers, the public, and the media on local governments. This acceleration in information retrieval related to government decision-making is beneficial for quick decision-making, fostering the improvement of government efficiency [40]. However, after the opening of HSR, there is a rapid flow of information, talent, and capital, making inter-governmental information

more open and transparent, enabling governments to compare and compete. In this context, governments with different efficiency levels face varying competitive pressures, leading to differences in the impact of HSR opening on regional economic growth [6].

For cities with sufficiently high government efficiency, where the scope for efficiency improvement is limited, and the competition pressure is relatively low, the willingness to improve efficiency is weaker. From the perspective of information flow, the increased information flow resulting from HSR opening may not significantly intensify the competitive pressure they face, thus having a relatively weaker impact on economic growth. However, for regions and cities with lower government efficiency, the rapid flow of information makes them quickly aware of the disparities with other governments, increasing their competitive pressure. This pressure compels the government to take action to promote efficiency, thereby driving the economic growth of the city. Therefore, compared to cities with high government efficiency, the opening of HSR in cities with lower government efficiency has a more pronounced impact on economic growth. Based on this, Hypothesis 2 is proposed:

H2. *Government efficiency has a negative impact on the relationship between HSR opening and regional economic growth.*

3.3. The Moderating Effect of the Innovation Environment

Innovation is a crucial engine for the healthy development of the economy, and the innovation environment serves as a network system that motivates and constrains the behavior of innovation entities, ensuring the realization of innovation. Innovation entities can effectively cultivate and demonstrate innovation vitality, driving the enhancement of regional innovation capability and economic growth, only within a certain innovation environment [41]. Existing research has mainly focused on the direct impact of high-speed rail opening on the innovation environment, suggesting that high-speed rail opening can optimize resource allocation along its route, improve the layout of industrial structures, accelerate the flow of innovation elements within the region [8], and meet the demand for high value-added innovation relying on face-to-face communication [42], thus exerting a favorable influence on the creation of an innovative environment [26].

However, the variations in the innovation environment following the opening of HSR may lead to significant differences among cities in terms of the attractiveness of innovation elements and the ability to apply and transform innovative outcomes. This discrepancy could, in turn, impact the relationship between HSR opening and economic growth. First, cities with a generally favorable innovation environment tend to have well-developed high-tech industries. The construction and operation of HSR can stimulate the further development of related upstream and downstream high-tech industries in cities along the route, thereby exerting a certain promoting effect on economic growth [27]. Second, after the opening of HSR, more innovators and innovation elements can freely move within the high-speed rail scope, breaking the knowledge exchange barriers caused by low connectivity in transportation. This drives knowledge exchange and interaction between different cities and regions, triggering "learning effects", "imitation effects", and "dissemination effects" [10]. Therefore, compared to cities with a less favorable innovation environment, the opening of high-speed rail in cities with a better innovation environment can rapidly enhance the efficiency of knowledge transfer and communication, accelerate the transformation and application of new technologies and knowledge within the city, promote innovation activities, and be more conducive to economic growth [43]. Additionally, unlike developed countries, regional economic growth in China benefits from the agglomeration effect generated by concentrated innovation activities [44]. The opening of high-speed rail can create a "time-space compression" effect, improving the accessibility between regions. For cities with a good innovation environment, increased accessibility implies a "siphon effect", allowing innovative elements such as knowledge and technology to gather more quickly from surrounding cities, thereby promoting the economic growth of these cities. Based on this, this study proposes Hypothesis 3:

H3. *The innovation environment has a positive impact on the relationship between HSR opening and regional economic growth.*

3.4. The Regional Heterogeneity of the Moderating Effects of Government Efficiency and Innovation Environment

The moderating effects of government efficiency and the innovation environment on the relationship between HSR development and economic growth are likely to depend significantly on the speed of aggregation and transmission of resources, talent, quality capital, and information, as well as variations in government efficiency and innovation environment among different cities [45]. In the context of central cities within urban clusters, peripheral cities within urban clusters, and non-urban cluster cities, the heterogeneity in the speed of resource and information transmission, as well as the differences in government efficiency and innovation environment, may introduce regional variations in the moderating effects.

First, considering the heterogeneity between urban cluster cities and non-urban cluster cities, before the introduction of HSR, other transportation infrastructures within urban clusters, such as highways and railways, are relatively well-developed, allowing for the aggregation and transmission of resources and information within a certain range [1]. The introduction of HSR accelerates this process, enhancing the scale and scope of resource and information aggregation and transmission [46]. Compared to non-urban cluster cities, the speed, scale, and scope of resource and information transmission within urban cluster cities are faster, larger, and broader. Hence, the moderating effects of government efficiency and the innovation environment on the relationship between HSR development and economic growth may exhibit regional heterogeneity between urban cluster cities and non-urban cluster cities.

Second, considering the heterogeneity between central cities and peripheral cities within urban clusters, central cities serve as the core regions for economic and social activities within urban clusters, exhibiting higher levels of economic development, well-established infrastructure, and relatively abundant resource accumulation. Minor improvements and optimizations in government efficiency and innovation environment may not significantly alter the speed of information transmission between cities and the perceived pressure on the government. This, in turn, may not substantially impact the degree to which HSR development influences economic growth. According to the "core-periphery" theory in new economic geography, the radiating effect from central to peripheral cities within urban clusters is limited. In contrast, peripheral cities in urban clusters often have weaker infrastructure and relatively limited resource reserves. Improved government efficiency and innovation environment, when combined with HSR development, can significantly alter the perceived competitive pressure and speed of information transmission for peripheral cities, influencing the extent to which HSR development stimulates economic growth. Thus, the moderating effects of government efficiency and innovation environment on the relationship between HSR development and economic growth may exhibit regional heterogeneity between central cities and peripheral cities within urban clusters. In summary, the following hypotheses are proposed:

H4. *The negative effect of government efficiency on the relationship between HSR opening and regional economic growth varies across central cities within urban clusters, peripheral cities within urban clusters, and non-urban cluster cities.*

H5. *The positive effect of the innovation environment on the relationship between HSR opening and regional economic growth exhibits regional heterogeneity among central cities within urban clusters, peripheral cities within urban clusters, and non-urban cluster cities.*

Based on the above analysis, the theoretical model of this paper is illustrated in Figure 1.

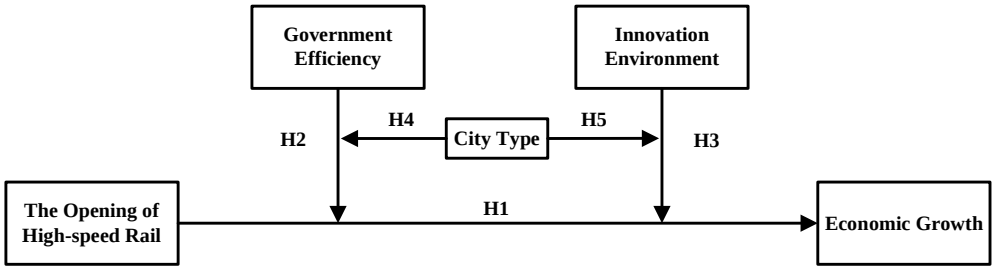


Figure 1. Theoretical model.

4. Methodology

4.1. Data and Samples

According to the main goals of China's "Thirteenth Five-Year Plan" for railway construction, by 2025, the high-speed rail mileage in China will reach 38,000 km, achieving interconnection among provincial capital cities and other large and medium-sized cities with a population of over 500,000. Therefore, for research related to the economic benefits of high-speed rail, China is a very suitable research subject. This paper takes Chinese prefecture-level cities as the research object, covering the period from 2003 to 2017. Following the definition in the "High-speed Railway Design Code" by the China National Railway Administration, high-speed rail refers to newly constructed passenger dedicated lines with a designed operation speed of 250 km/h or above (including reserved speeds), and an initial operational speed of no less than 200 km/h. High-speed rail-related data are obtained from the Chinese Research Data Services Platform (CNRDS), and city-level data are sourced from the annual "China City Statistical Yearbook". After removing data with missing major variables, a total of 3748 observations from 297 cities were obtained.

4.2. Models

Due to variations in the timing of HSR implementation across different cities, it is not feasible to uniformly define the time of HSR opening for all cities. The multi-period differences-in-differences method can assess the net effects of policy implementation when the timing of policy implementation varies. Therefore, this paper adopts the multi-period differences-in-differences method to estimate the impact of HSR opening on urban economic growth. The econometric model is as follows, and Table 1 lists the representative meanings of each symbol in the formula:

$$EG_{i,t} = \alpha_0 + \alpha_1 HSR \times Post + \alpha_3 C_{i,t} + Year_t + City_i + \varepsilon_{i,t} \quad (1)$$

Table 1. Symbol table.

Symbol	Representative Meaning
i	city
t	year
$EG_{i,t}$	the economic growth status of city i in year t
HSR × Post	the interaction term indicating whether the city opened a HSR during the sample observation period and whether it opened in the current year
GE	government efficiency
IE	innovation environment
$C_{i,t}$	a set of control variables including economic agglomeration, employment agglomeration, urbanization level, industrial structure, and population size
$Year_t$	the dummy variable for year effects
$City_i$	the dummy variable for city-specific effects
ε_{it}	the random disturbance term

To examine the moderating effects of government efficiency and innovation environment on the relationship between high-speed rail opening and economic growth, this paper sequentially includes the interaction terms of government efficiency and innovation environment with HSR opening in the model. The econometric model is as follows:

$$EG_{i,t} = \alpha_0 + \alpha_1 HSR \times Post + \alpha_3 GE + \alpha_4 GE \times HSR \times Post + \alpha_5 C_{i,t} + Year_t + City_i + \varepsilon_{i,t} \quad (2)$$

$$EG_{i,t} = \alpha_0 + \alpha_1 HSR \times Post + \alpha_3 IE + \alpha_4 IE \times HSR \times Post + \alpha_5 C_{i,t} + Year_t + City_i + \varepsilon_{i,t} \quad (3)$$

$$EG_{i,t} = \alpha_0 + \alpha_1 HSR \times Post + \alpha_3 GE + \alpha_4 GE \times HSR \times Post + \alpha_5 IE + \alpha_6 IE \times HSR \times Post + \alpha_7 C_{i,t} + Year_t + City_i + \varepsilon_{i,t} \quad (4)$$

4.3. Variables Measurement

Economic Growth (EG): Drawing on established research methodologies for measuring economic growth [9,47], this study employs the natural logarithm of the regional gross domestic product (GDP) for each city as a measure of economic growth during each year of the sample observation period.

High-Speed Rail Opening (HSR × Post): The variable for high-speed rail opening is represented by an interaction term indicating whether a city opened a HSR during the sample observation period and whether it opened in the specific year of observation (Post). If a city opened a high-speed rail during the sample period, HSR is coded as 1; otherwise, it is coded as 0. If a city opened a high-speed rail in a specific year, Post is coded as 1 for that year and subsequent years, and 0 for years prior to the opening.

Government Efficiency (GE): Drawing on public choice theory [20], government efficiency is defined through a relative comparison of inputs and outputs [20]. The output indicators encompass three dimensions—education level (total number of staff and students in regular higher education institutions), infrastructure level (road mileage and electricity generation), and the level of health condition development (number of health technical personnel and bed capacity in medical and health institutions). Meanwhile, local fiscal general budget expenditures are considered as government input indicators, and government efficiency is estimated using Data Envelopment Analysis (DEA) [18].

Innovation Environment (IE): Referring to the definition of the innovation environment in the evaluation index system for China's urban business environment [48], the innovation environment is measured using scientific expenditures and the innovation capability index, with equal weights of 0.5 assigned to both indicators, as shown in Formula (5) [44].

$$IE = 0.5 \times \text{scientific expenditures} + 0.5 \times \text{innovation capability index} \quad (5)$$

In addition, this study includes Economic Agglomeration (ECA), Employment Agglomeration (EMA), Urbanization Level (UL), Industrial Structure (IS), and Population Size (PS) as control variables. Economic agglomeration is measured by the ratio of the sum of the output value of the second and third industries in the city to the construction land area of that city. Employment agglomeration is represented by the ratio of the sum of employees in the second and third industries in the city to the construction land area. Urbanization level is indicated by the ratio of the built-up area to the municipal area. Industrial structure is expressed by the proportion of the second industry to the regional GDP of the city. Population size is represented by the natural logarithm of the total population in the city at the end of the year.

5. Results

5.1. Descriptive Statistics and Correlation Analysis

As can be seen from Table 2, there is a significant positive correlation between the opening of HSR and economic growth ($\beta = 0.658$, $p < 0.01$), which lays a preliminary foundation for this paper to explore the impact of HSR opening on economic growth. However, because the control variables will affect the final regression results, it is necessary to conduct further multiple regression tests. In addition, the multicollinearity test was

carried out on the variables in this paper, and the results showed that the VIF values of the variables were all between 1.16 and 1.52, with an average value of 1.36, which was much lower than the threshold value of 10 set by the previous research. Therefore, there is no obvious multicollinearity problem between the variables.

Table 2. Descriptive statistics and correlation coefficient.

Variables	M	SD	EG	HSR × Post	GE	IE	ECA	EMA	UL	IS	PS
EG	17.915	0.823	1								
HSR × Post	0.525	0.501	0.658 ***	1							
GE	0.544	0.227	0.010 ***	0.161 ***	1						
IE	38.287	20.088	−0.120	0.229 *	0.014	1					
ECA	11.733	1.010	−0.096	0.043	−0.151 ***	−0.051	1				
EMA	1.582	4.023	0.389 ***	0.455 ***	0.176 ***	0.007	0.378 ***	1			
UL	0.158	0.105	0.009	0.188 *	0.099 ***	0.448 ***	−0.015	0.068	1		
IS	43.852	9.396	−0.455 ***	−0.253 *	−0.034 *	−0.126	0.046	−0.260 **	0.190 *	1	
PS	7.052	0.622	0.309 ***	0.035	0.183 ***	−0.436 ***	−0.277 **	−0.046	−0.295 **	−0.203 *	1

Note: *, **, and *** represent significance at the 10%, 5%, and 1% levels, respectively.

5.2. Regression Analysis

This paper employs a two-way fixed effects model with fixed year and individual effects for regression analysis. The baseline regression results are presented in Table 3. Model 1 represents the impact of HSR opening on urban economic growth, Model 2 examines the moderating effect of government efficiency on the relationship between HSR opening and urban economic growth, and Model 3 explores the moderating effect of the innovation environment on the relationship between HSR opening and urban economic growth. The results of Model 1 indicate a positive correlation between HSR opening and economic growth ($\beta = 0.032$, $p < 0.05$), confirming H1 that HSR opening significantly promotes urban economic growth. Model 2 results reveal a significantly negative interaction between HSR opening and government efficiency ($\beta = -0.080$, $p < 0.1$), supporting H2 that government efficiency has a negative impact on the relationship between HSR opening and economic growth. Model 3 results show a significant positive interaction between HSR opening and the innovation environment at the 1% significance level ($\beta = 0.005$, $p < 0.01$), supporting H3 that the innovation environment has a positive impact on the relationship between HSR opening and economic growth.

5.3. Heterogeneity Test of Moderating Effects

This paper divides Chinese cities into central cities of urban agglomerations, peripheral cities of urban agglomerations, and non-urban agglomeration cities according to the list of approved and pending urban agglomeration names, grouping them for regression to test the heterogeneity of moderating effects among different types of cities. The regression results in Table 4 show that, for central cities of urban agglomerations, the interaction terms of high-speed rail (HSR) with government efficiency (GE) and innovation environment (IE) are not significant, indicating that government efficiency and innovation environment do not significantly impact the relationship between HSR opening and economic growth. For peripheral cities of urban agglomerations, the interaction term of HSR opening with government efficiency is significantly negative at the 5% significance level ($\beta = -0.195$, $p < 0.05$), suggesting that government efficiency has negative impact on the relationship between HSR opening and economic growth. The interaction term of HSR opening with innovation environment is significantly positive ($\beta = 0.005$, $p < 0.01$), indicating that innovation environment has positive impact on the relationship between HSR opening and economic growth. For non-urban agglomeration cities, the interaction terms of HSR with government efficiency and innovation environment are not significant, indicating that government efficiency and innovation environment do not have impact on the relationship between HSR opening and economic growth. These results suggest that the moderating effects of government efficiency and innovation environment exhibit regional heterogeneity

among central cities of urban agglomerations, peripheral cities of urban agglomerations, and non-urban agglomeration cities, supporting H5. This is mainly because central cities of urban agglomerations already have relatively high government efficiency and good innovation environments. Therefore, slight improvements in government efficiency and innovation environment may not have impact on the relationship between HSR opening and economic growth. In contrast to urban agglomeration cities, non-urban agglomeration cities are relatively isolated and restricted in development, with slow speeds of resource and information transmission, small scale, and narrow scope. Even after the opening of HSR, the differences between governments are difficult to manifest, and the perceived competitive pressure of governments is relatively low. The flow speed of innovation elements and information is relatively slow, and the moderating effects of government efficiency and innovation environment may not be significant.

Table 3. Results of baseline regression.

Variables	(1) EG	(2) EG	(3) EG
HSR × Post	0.032 ** (0.015)	0.083 ** (0.032)	−0.128 *** (0.032)
GE	−0.004 (0.020)	0.006 (0.022)	
HSR × Post × GE		−0.080 * (0.049)	
IE	0.004 *** (0.001)		0.002 ** (0.001)
HSR × Post × IE			0.005 *** (0.001)
ECA	0.592 *** (0.050)	0.592 *** (0.050)	0.603 *** (0.048)
EMA	−0.544 *** (0.049)	−0.544 *** (0.049)	−0.555 *** (0.048)
UL	0.184 * (0.111)	0.185 * (0.111)	0.154 (0.106)
IS	0.003 ** (0.001)	0.003 ** (0.001)	0.003 ** (0.001)
PS	0.238 *** (0.071)	0.251 *** (0.073)	0.220 *** (0.068)
Urban fixed effect	Yes	Yes	Yes
Year fixed effect	Yes	Yes	Yes
Constant	6.466 *** (0.774)	6.475 *** (0.786)	6.453 *** (0.742)
N	3748	3748	3748
R2	0.948	0.947	0.950

Note: *, **, and *** represent significance at the 10%, 5%, and 1% levels, respectively.

5.4. Parallel Trends Test and Dynamic Test

The difference-in-differences estimation method requires that the economic growth of all cities be parallel before the opening of high-speed rail. Drawing on the testing method by Beck et al. [49], we selected the seven years before and after the opening of HSR as the observation period and included dummy variables for each year in the regression model to verify the parallel trends assumption. Figure 2 displays the estimated values and 95% confidence intervals for the dummy variables for each year over the 15 years before and after the opening of HSR. The x-axis in Figure 2 represents the difference between the

years when the high-speed rail opened, and the unit is year; the y-axis represents economic growth. The dummy variables for the first seven years before the opening of high-speed rail are not significantly different from zero, confirming the parallel trends. The dynamic effect test after the opening of HSR shows that the dummy variables for the seven years after the opening are mostly significantly different from zero. Moreover, with the extension of the time since the opening of HSR, the differences in economic growth before and after the opening of HSR become more pronounced.

Table 4. Heterogeneity test.

Variables	Central City of Urban Agglomeration		Peripheral Cities of Urban Agglomerations		Non-Urban Agglomeration City	
	(4)	(5)	(6)	(7)	(8)	(9)
HSR × Post	0.042 (0.080)	0.078 (0.168)	0.125 ** (0.043)	−0.151 *** (0.040)	0.118 (0.081)	−0.003 (0.054)
GE	−0.026 (0.067)		0.007 (0.030)		0.015 (0.030)	
HSR × Post × GE	−0.032 (0.107)		−0.195 ** (0.063)		−0.125 (0.119)	
IE		0.001 (0.002)		0.002 ** (0.001)		0.003 ** (0.001)
HSR × Post × IE		−0.001 (0.004)		0.005 *** (0.001)		0.002 (0.002)
ECA	0.593 *** (0.086)	0.591 *** (0.087)	0.554 *** (0.063)	0.569 *** (0.060)	0.497 *** (0.064)	0.501 *** (0.061)
EMA	−0.536 *** (0.082)	−0.533 *** (0.086)	−0.506 *** (0.061)	−0.520 *** (0.059)	−0.393 *** (0.065)	−0.399 *** (0.063)
UL	0.053 (0.219)	0.069 (0.207)	0.155 (0.114)	0.150 (0.111)	−0.015 (0.092)	−0.031 (0.094)
IS	−0.001 (0.003)	−0.001 (0.003)	0.003 * (0.002)	0.003 ** (0.002)	0.009 *** (0.002)	0.009 *** (0.002)
PS	0.085 ** (0.040)	0.086 * (0.043)	0.174 ** (0.078)	0.148 ** (0.072)	0.188 ** (0.081)	0.189 ** (0.081)
Urban fixed effect	Yes	Yes	Yes	Yes	Yes	Yes
Year fixed effect	Yes	Yes	Yes	Yes	Yes	Yes
Constant	8.552 *** (1.071)	8.519 *** (1.065)	7.372 *** (0.936)	7.275 *** (0.889)	7.212 *** (0.833)	7.118 *** (0.799)
N	444	444	2328	2328	976	976
R2	0.958	0.958	0.949	0.950	0.955	0.955

Note: *, **, and *** represent significance at the 10%, 5%, and 1% levels, respectively.

5.5. Robustness Test

5.5.1. Instrumental Variable Method to Control Endogeneity Issues

The issue of endogenous selection exists regarding whether a city opens HSR. For cities, there may be certain unobservable factors that simultaneously influence the opening of HSR and economic growth over time. Therefore, drawing on research by Liu and Zhou [50], this study selects the terrain fluctuation of prefecture-level cities as an instrumental variable. The main reasons are as follows: first, in terms of correlation requirements, the difficulty and cost of constructing HSR will significantly increase with the terrain fluctuation of the city, thereby affecting the decision to open HSR [8]. Second, in terms of exogeneity requirements, terrain fluctuation, as a geographical feature, is objectively present and not directly related to economic growth [50]. In addition, since terrain fluctuation does not

change over time, this study borrows the method from Zhang and Li [51], multiplying it by the number of cities in each province opening HSR each year, and uses Two-Stage Least Squares (2SLS) to control endogeneity. Specifically, in the first stage, the prediction value is obtained by regression between endogenous variable, instrumental variable, and exogenous variable, aiming at replacing endogenous variable. The second stage is to make regression between the explained variable and Prediction, exogenous variable, and obtain the final result. The estimation results are shown in Table 5.

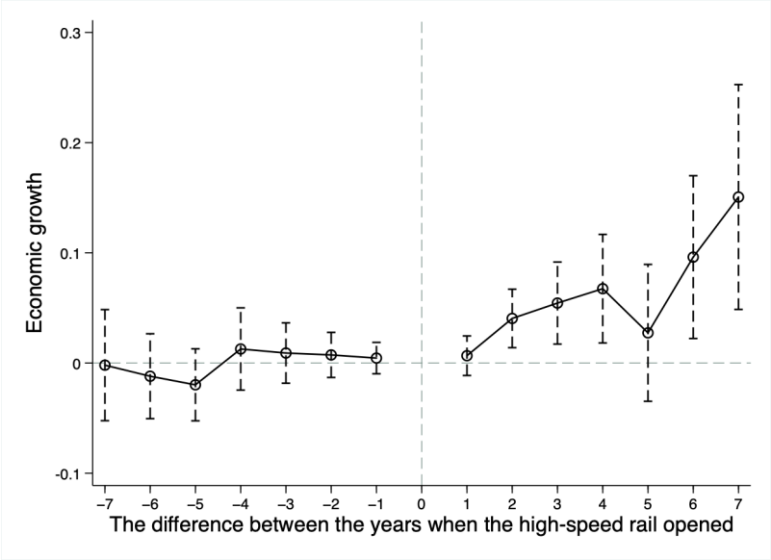


Figure 2. Parallel trend and dynamic effect test.

Table 5. 2SLS Results of tool variable.

	(10) **Stage 1** **HSR × Post**	**(11)** **Stage 2** **EG**
Prob(HSR × Post)		1.272 *** (0.148)
IV	0.032 *** (0.003)	
Controls	Yes	Yes
Constant	0.130 (0.099)	10.617 *** (0.180)
Urban fixed effect	Yes	Yes
Year fixed effect	Yes	Yes
N	3591	3591
R2	0.337	0.597
F	146.811	

Note: *** represent significance at the 1% levels.

From Table 5, it can be observed that there is a significant positive correlation between HSR opening and economic growth ($\beta = 1.272$, $p < 0.01$), consistent with the baseline results, indicating that the opening of HSR significantly promotes regional economic growth. Meanwhile, the first-stage results show that the instrumental variable (IV) is positively correlated with HSR opening ($\beta = 0.032$, $p < 0.01$), and the F-statistic is 146.811, far exceeding the critical value for identifying weak instrumental variables at the 10% significance level. This indicates the effectiveness of the instrumental variable selected in this study. The

analysis above demonstrates that the research findings remain robust after controlling for endogeneity issues.

5.5.2. Replace the Explained Variable

In the above regression analysis, this study used the natural logarithm of the regional Gross Domestic Product (GDP) for each city to measure the economic growth over the observation period. According to Zhang and Zhang [52], the Keqiang Index, introduced by the well-known British economic magazine "The Economist", better reflects the real situation of China's economic growth. Therefore, in robustness tests, this study constructed the Keqiang Index (see Formula (6)) as an alternative variable for economic growth and re-conducted the regression analysis to test the robustness of the research results, as shown in Table 6. Model 12 indicates a significant positive correlation between HSR opening and the Keqiang Index ($\beta = 0.037$, $p < 0.05$). Model 13 shows that the interaction term between HSR opening and government efficiency is significantly negative ($\beta = -0.162$, $p < 0.1$), indicating a negative moderating effect of government efficiency on the relationship between HSR opening and the Keqiang Index. Model 14 reveals that the interaction term between HSR opening and innovation environment is significantly positive ($\beta = 0.001$, $p < 0.01$), indicating a positive moderating effect of the innovation environment on the relationship between HSR opening and the Keqiang Index. The analysis above suggests that the research findings in this study are robust.

$$\begin{aligned}\text{Keqiang Index} = {} & \text{industrial electricity consumption} \times 0.4 + \\ & \text{balance of medium and long} - \text{term bank loans} \times 0.35 + \text{railway freight volume} \times 0.25\end{aligned} \quad (6)$$

Table 6. Impact of the opening of high-speed rail on economic growth (as measured by the Keqiang index).

Variables	(12)	(13)	(14)
HSR × Post	0.037 ** (0.155)	0.138 ** (0.056)	−0.250 *** (0.431)
GE	0.116 *** (0.034)	0.141 *** (0.039)	
HSR × Post × GE		−0.162 * (0.090)	
IE	0.004 *** (0.001)		0.001 (0.001)
HSR × Post × IE			0.001 *** (0.001)
ECA	−0.009 (0.018)	−0.008 (0.018)	0.009 (0.015)
EMA	0.005 (0.018)	0.004 (0.181)	−0.014 (0.015)
UL	0.117 (0.087)	0.117 (0.086)	0.071 (0.072)
IS	−0.004 ** (0.001)	−0.004 *** (0.001)	−0.003 *** (0.001)
PS	0.136 * (0.076)	0.146 * (0.007)	0.107 * (0.055)
Urban fixed effect	Yes	Yes	Yes
Year fixed effect	Yes	Yes	Yes
Constant	−0.915 * (0.467)	−0.901 * (0.476)	−0.871 * (0.353)
N	3591	3591	3591
R2	0.943	0.945	0.946

Note: *, **, and *** represent significance at the 10%, 5%, and 1% levels, respectively.

6. Conclusions and Implications

The construction and development of transportation infrastructure are crucial for driving urban economic growth. In recent years, the rapid development of HSR in China has sparked interest among domestic and international scholars in researching the relationship between HSR opening and economic growth. However, consensus has not yet been reached in the academic community on this impact, necessitating further exploration of situational factors influencing the impact of HSR opening on economic growth. This study takes 297 Chinese cities from 2003 to 2017 as the research sample, employs the multiple-period difference-in-differences method to study the impact of HSR opening on economic growth, and further explores the moderating effects of government efficiency and innovation environment on the relationship between HSR opening and economic growth from the perspectives of government competition pressure and information flow. Empirical results reveal that: firstly, HSR opening significantly enhances economic growth in the regions along the rail lines; secondly, government efficiency has negative impact on the promoting effect of HSR opening on economic growth, indicating a stronger promoting effect for cities with lower government efficiency; innovation environment has positive impact on the promoting effect of HSR opening on economic growth, indicating a stronger promoting effect for cities with a better innovation environment. Lastly, the moderating effects of government efficiency and innovation environment on the relationship between HSR opening and economic growth exhibit regional heterogeneity among central cities of urban agglomerations, peripheral cities of urban agglomerations, and non-urban agglomeration cities. The moderating effects of innovation environment and government efficiency are significant for peripheral cities of urban agglomerations but not significant for central cities of urban agglomerations and non-urban agglomeration cities. Additionally, robustness tests using instrumental variable methods and replacing the dependent variable (using the Keqiang Index instead of the economic growth variable) yield consistent results, confirming the robustness of the research findings.

According to the conclusions of this study, the following policy recommendations are proposed:

First, for underdeveloped regions and cities on the periphery of urban clusters, it is essential to fully leverage the stimulative effect of HSR on urban economic growth. HSR, on one hand, compresses spatial distances, facilitating the flow of labor, resources, and information, creating employment opportunities along the HSR corridor, enhancing market consumption capacity, and, on the other hand, optimizing the efficiency of enterprise resource allocation, improving overall productivity, ultimately fostering urban economic growth. Although the construction and operation of HSR may impose short-term fiscal pressures on the government, in the long run, it rapidly enhances inter-city accessibility, promotes regional economic collaboration, playing a crucial role in driving urban economic growth. Therefore, local governments should formulate corresponding policies and systems to continuously optimize the environment for economic growth, vigorously promote HSR construction and network formation, enhance the attractiveness of cities for superior resources and high-end talent, and drive regional economic development.

Second, in terms of government efficiency, for cities with relatively lower efficiency, expediting the construction and operation of HSR is necessary to facilitate information flow between these cities and others. This approach increases competitive pressure on local governments, compelling them to take actions to enhance efficiency and stimulate economic growth. Regarding the innovation environment, governments should intensify efforts to optimize urban innovation environments, minimizing the outflow of advantageous resources and innovation factors. Accelerating the transformation and application of new technologies and knowledge within urban regions, fully harnessing the positive regulatory effect of the innovation environment, creates favorable conditions for HSR to promote economic growth.

Third, for cities on the periphery of urban clusters, local governments should carefully balance the “suction effect” and “spillover effect” brought about by HSR. Implementing

supportive policies to enhance the innovation environment will aid these cities in interacting and exchanging information with central cities, learning and absorbing core technologies and resources, reducing the outflow of high-quality capital and talent, and stimulating economic growth. For non-urban cluster cities, local governments should employ measures such as constructing and improving transportation infrastructure to integrate more rapidly into metropolitan areas and urban clusters, providing new impetus for the coordinated, healthy, and sustainable development of the economy.

This paper still possesses some limitations that warrant improvement in future research. Firstly, it exclusively examines the impact of high-speed rail openings on economic growth while overlooking the potential significance of the number of high-speed rail stations and lines. Future studies could delve into further analysis of how the quantity of high-speed rail stations and lines may contribute to economic growth. Secondly, the paper solely classifies urban types based on urban agglomerations. Future research could consider factors such as regional distribution and economic development status as criteria for classifying urban types, thereby exploring the heterogeneity among different cities.

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