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Constant or Increasing Returns? The Role of High-Speed Rail in Reshaping Urban Economic Disparities Across China's Different City Tiers

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Abstract: The development of high-speed rail (HSR) is widely regarded as a catalyst for economic growth, yet its implications for regional and urban equity remain contested. To systematically examine the urban-level impacts of HSR, this study constructs a novel theoretical framework integrating New Economic Geography and Neoclassical Growth Theory, advancing the understanding of how transport infrastructure reshapes economic convergence across different city tiers. Using panel data from 287 prefecture-level cities in China (2008–2020), the study employs a baseline convergence model, a spatial convergence model with HSR and a moderation model to address four key questions: (1) whether HSR alters the classic convergence pattern knowing as Constant Returns to Scale, leading to multiple equilibria or divergence; (2) whether HSR's economic effects differ across cities with varying development levels; (3) how HSR-enhanced accessibility and connectivity interacts with initial development conditions to moderate the speed of convergence; and (4) what spatial spillover effects HSR generates for neighboring cities. The results reveal that HSR functions as an equalizing infrastructure, moderating growth in advanced urban areas while accelerating catch-up growth in less developed cities through positive spillovers, thereby fostering greater inter-city economic balance. This study contributes to urban and regional scholarship by delineating the nuanced mechanisms through HSR reconfigures city-level growth trajectories and spatial hierarchies. Policy-wise, this study emphasizes the need for an integrated HSR network planning to harness its convergence-enhancing potential and support coordinated urban development.

Keywords: High-Speed Rail (HSR); Convergence; Regional Economic Inequality; Spatial Spillovers; Solow Model.

1. Introduction

Major transport infrastructures were recognized as a significant driver in economic growth worldwide. As a pivotal breakthrough in passenger rail technology, High-Speed Rail (HSR) systems are characterized by their high speed, frequency, reliability, and comparative cost-effectiveness, offering a compelling alternative to other modes of travel. Besides, its development was considered to generate positive spillover effects, i.e., job creation, the integration of regional markets, and a profound "space-time compression" that reshapes economic geographies. Extensive literature examining the multifaceted economic effects of HSR converges on the consensus that transport infrastructure can serve as a fundamental catalyst for regional economic growth and prosperity (Wang et al., 2018; Wetwitoo & Kato, 2017; Xiao, 2020).

While there is a rising concern about economic imbalance induced by the development of HSR. Global evidence suggests that HSR may exacerbate regional imbalance due to the uneven distribution of accessibility benefits, illustrating that its role in mitigating inequality within regions remains inconsistent (Cascetta et al., 2020; Yoo et al., 2023, 2024). Existing literatures tend to explain how transportation infrastructure influences economic activity through several key factors, i.e., labor migration and industrial relocation, towards New Economic Geography (NEG) theory (Krugman, 1991). This perspective, however, has often overlooked critical insights from Neoclassical Growth Theory (NGT), especially regarding the mechanisms of economic convergence. In the context of regional disparities, although NGT offers a foundational framework for understanding convergence, it remains unclear whether its assumption of constant

returns to scale remains robust under the influence of HSR, or whether, consistent with NEG prediction, the presence of HSR transforms homogeneous convergence into divergence or multiple equilibria. Furthermore, significant heterogeneity in the impacts of HSR across cities of different development tiers remains underexplored, pointing to a clear gap in the current understanding of how HSR effects vary with regional economic contexts.

In this study, the association between HSR and regional economic disparities is empirically investigated across the prefecture-level cities in China across different city tiers. Leveraging panel data from 287 cities over the period 2008-2020, this research carries out econometric analysis based on NGT and NEG theory, aiming to provide answers to the following questions: (1) To what extent does HSR contribute to regional economic imbalance? (2) How does HSR-induced accessibility/connectivity moderate the rate of regional economic convergence through its interaction with initial economic conditions? (3) What are the spatial spillover effects of HSR on the economic development of neighboring regions? and (4) What are the heterogeneous effects of HSR across different city tiers of China? This approach offers a novel perspective on the economic consequences of HSR, advancing the discourse beyond traditional discussions of economic development and regional imbalance. A significant strength of this study is the comprehensive analysis of effects caused by both “accessibility” and “connectivity” due to the expansion of HSR to economic disparities. Regarding the control variables, this study adopts factors commonly considered in classical transportation economics research, incorporating industrial upgrading, government scale, and the development of

other transportation infrastructures. In terms of the empirical model, to address potential endogeneity issues, a Fixed-Effects Panel Model and a Spatial Durbin Model are employed to mitigate the impact of endogeneity as effectively as possible. The analysis also applies to other transportation infrastructure, i.e., seaport, airport, and highway, across regions that affect accessibility and connectivity.

2. Literature review

The different perspectives on whether HSR could lead to regional economic disparities were widely discussed.

One stream of studies demonstrates that HSR could narrow the economic disparities. It is stated that HSR networks would facilitate the flow of knowledge and technology from advanced to less developed regions, thereby promoting industrial upgrading and restructuring in lagging areas (Jin & Zhu, 2023). And it is believed that HSR could foster the innovation output in connected cities by enhancing collaboration and attracting skilled labor, which significantly strengthens their ability to withstand economic shocks and contributes to a more balanced regional development (Li et al., 2023). Meanwhile, an analysis of the Italian experience reveals that HSR could alleviate regional inequality primarily by dramatically improving the accessibility of peripheral and less developed areas, integrating them into mainstream economic networks (Di Matteo & Cardinale, 2023). Furthermore, empirical evidence from panel data illustrates that the spatial integration effects of HSR, through significantly improved accessibility, would promote regional economic convergence by enabling a more efficient diffusion of economic activities across regions (Chen & Haynes, 2017).

While another stream of studies stated that HSR could intensify regional imbalance. For instance, Jiao et al. (2017). illustrate that HSR would increase the inequality of nodal centrality according to the weighted closeness centrality indicator, reinforcing the dominance of large cities in the network. Similarly, F. Wang et al. (2022). identify that HSR could induce economic agglomeration in major urban areas among nine provinces along the Yellow River in China, causing population loss and economic decline in small and medium-sized cities, thereby widening regional disparities. Moreover, when analyzing the synergistic effects of HSR and megalopolis policies, it was found that these combined measures have conferred disproportionate benefits on the economically developed regions, thereby widening the development gap between different regions (Yang et al., 2020). Additionally, a quasi-natural experiment, conducted with the introduction of HSR as the core variable, revealed that the effect of HSR on enhancing the quality of urban economic growth is significantly stronger in regional centers and eastern cities, thus highlighting the existence of spatial inequities (Kong et al., 2022). Finally, panel data confirms that HSR programs deliver highly heterogeneous local economic benefits, with larger gains focused on industrialized, well-connected cities, further widening inequalities across locations and routes (Ke et al., 2017).

The very nature of these effects can be systematically analyzed via the Solow Model by NGT, highlighting the roles of labor, capital, and innovation as the key transmission channels for HSR's economic influences. As to labor migration, existing studies suggest that HSR has significantly reduced intercity travel times and enhanced mobility for the densely distributed labor, stimulating economic interaction and prosperity

among connected urban centers (Cheng et al., 2015; Ke et al., 2017). In terms of capital mobility, it is stated that HSR-connected cities experience faster growth of capital stock, indicating that a stronger mobility occurs and thus contributes to the change of the regional economy (Duan et al., 2021). For the innovation, it is demonstrated that HSR improves the level of innovation significantly, especially in peripheral and small cities (Fan & Xu, 2023).

Meanwhile, the effects of HSR on regional imbalance can be interpreted through the lens of NEG theory, and such mechanism operates through the heterogeneous enhancement of regional accessibility and connectivity, the consequent redistribution of industrial structures, and the facilitation of knowledge spillovers within the HSR network. Regarding the heterogeneous enhancement of accessibility and connectivity, it is believed that HSR could improve the accessibility of non-HSR cities, motivate inflow to these cities, and enhance spatial economic integration (Li et al., 2016). Evidence proves that cities in Western China with longer initial travel times enjoy a greater rail time reduction than other regions (Liu & Zhang, 2018). From the perspective of the redistribution of industry, the study demonstrates that HSR leads to a greater sectoral specialization across less economically advanced regions (Chen & Vickerman, 2017). And (Li et al., 2020) identify the positive effect of HSR on increasing economic efficiency, especially in the service industry, indicating the promotion to structural upgrading. As to flows of knowledge, study proves HSR network enhances the high-skilled sector's concentration in connected regions (Shi et al., 2025), suggesting more highly productive scientists migrate to the HSR cities and bring more production (Dong et al.,

2020).

Existing studies have primarily focused on limited aspects of the mechanisms behind HSR's effects, i.e., capital mobility, labor migration, or industrial structure, yet they lack a systematic perspective. Meanwhile, these literatures fail to provide a comprehensive assessment of HSR's effects, as it generally captures only the presence or absence of HSR services by using a binary variable, or considers only accessibility or connectivity in isolation. Little study has yet integrated both accessibility and connectivity within an NGT framework to comprehensively examine HSR's influence on regional economic disparities from a convergence perspective. Furthermore, there still remains a concern about how HSR contributes to patterns of development across different city tiers.

To address this research gap, the contributions of this study are as follows: (1) This study extends and integrates the NEG theory with NGT to develop a novel theoretical framework to capture whether HSR changes constant returns scale into increasing returns scale. (2) This study comprehensively measures HSR accessibility and connectivity, capturing not only the effect of HSR infrastructure development but also the intensity of HSR operations. (3) This study extends the traditional convergence model to account for HSR's spatial spillover effects and, more importantly, its moderating role in the convergence speed of cities at different development levels. (4) This study captures the heterogeneous effects of HSR across Chinese cities by conducting subgroup analyses.

3. Theoretical framework

3.1 Theoretical basis

3.1.1 New Economic Geography Theory

As posited by NEG theory, the coexistence of these two dual effects, namely agglomeration and spillover, calls for empirical investigation to determine whether HSR infrastructure helps narrow regional economic disparities (Krugman, 1991). A critical research priority is to quantify the magnitude of this convergence or divergence effect and clarify the specific mechanisms through which HSR shapes regional economic outcomes. A growing body of research rooted in NEG theory has examined the economic implications of HSR development. E.g., Jia et al (2017). employ transportation cost mechanisms to examine the HSR-economic growth nexus, revealing nuanced spatial interaction patterns. To extend the analytical framework, Z. Chen & Haynes (2017) propose a multidimensional pathway model encompassing information diffusion enhancement, market accessibility expansion, capital-labor factor mobility, and productivity convergence mechanisms.

Building on these findings, (Wang et al., 2023). demonstrate that HSR infrastructure significantly accelerates the optimization of industrial structures, the integration of labor markets, the advancement of urbanization processes, and the improvement of transportation network efficiency via longitudinal case analysis. Concurrently, Tian et al. (2023) develop a dual-effect paradigm that systematically differentiates between HSR-induced agglomeration economies and knowledge spillover dynamics. Through empirical investigation, Liang et al. (2020) identify the significant spatial heterogeneity

in HSR impacts, particularly noting the moderating effects of population density gradients, industrial composition characteristics, and capital absorption capacities in less-developed regions. Thus, NEG theory is a well-developed theoretical basis explaining the effect of HSR on the regional economy.

3.1.2 Neo-classical Growth Theory

As a foundational framework in economic growth theory, the Solow Model in NGT offers the key insights into the mechanisms driving economic expansion. It posits that economies converge toward distinct steady-state levels determined by capital accumulation, labor force growth, and technological progress. During this transitional phase, economies with lower initial development levels tend to experience more rapid growth, leading to conditional convergence across regions. According to the Solow Model, a production function is provided:

$$Y = F(K_t, L_t) \tag{1}$$

In the function above, Y means Economic output and is determined by K (capital stock) and L (labor). The function is a power function. Following Mankiw et al. (1992)'s research, production is augmented by adding human capital (H) to overcome shortcomings of the textbook Solow Model. Their Cobb–Douglas production function explicitly includes the level of technology (A).

$$Y = F(K_t, L_t, A_t, H_t) = \emptyset {K_t}^{\alpha} {H_t}^{\gamma} (A_t L_t)^{1-\alpha-\gamma} \tag{2}$$

To get per capital output, we divide Y with effective labor:

$$y = Y/AL = k^{\alpha} h^{\gamma} \tag{3}$$

The increase of physical capital and human capital can be expressed as:

$$\Delta k = k_t - k_{(t-1)} = s_k f(k_t) - (\delta + g + n)k_t \quad (4)$$

$$\Delta h = h_t - h_{(t-1)} = s_h f(h_t) - (\delta + g + n)h_t \quad (5)$$

When steady state is reached, assumingΔk =Δh =0

$$0 = {k_t}^* - {k_{t-1}}^* = s_k f({k_t}^*) - (\delta + g + n){k_t}^* \quad (6)$$

$$0 = {h_t}^* - {h_{t-1}}^* = s_h f({h_t}^*) - (\delta + g + n){h_t}^* \quad (7)$$

Thus ${k_t}^*$and ${h_t}^*$are no more a function of time but a constant, which can be expressed:

$${k_t}^* = \left(\frac{\emptyset {s_k}^{1-\gamma} {s_h}^{\gamma}}{\delta+g+n}\right)^{\frac{1}{1-\alpha-\gamma}} \quad (8)$$

$${h_t}^* = \left(\frac{\emptyset {s_k}^{\alpha} {s_h}^{1-\alpha}}{\delta+g+n}\right)^{\frac{1}{1-\alpha-\gamma}} \quad (9)$$

Bring ${k_t}^*$ ${h_t}^*$ into per capital output function:

$$y = \phi \left(\frac{\emptyset {s_k}^{1-\gamma} {s_h}^{\gamma}}{\delta+g+n}\right)^{\frac{1}{1-\alpha-\gamma}} \left(\frac{\emptyset {s_k}^{\alpha} {s_h}^{1-\alpha}}{\delta+g+n}\right)^{\frac{1}{1-\alpha-\gamma}} = \phi \frac{1+\alpha+\gamma}{z} {s_k}^{\frac{\alpha}{z}} {s_h}^{\frac{\gamma}{z}} (\delta + g + n)^{-\frac{(\alpha+\gamma)}{z}} \quad (10)$$

$$z = \frac{1}{1-\alpha-\gamma} \quad (11)$$

Assuming that capital depreciates at a constant rate and taking the logarithm of the equation, when output per capita (y) reaches its steady-state level:

$$log(y) = \beta_1 log(s_k) + \beta_2 log(s_h) + \beta_3 log(\delta + g + n) + \mu \quad (12)$$

If y deviates from its steady state, setting the time interval to 1 unit and referencing the derivation in (DURLAUF, SN et al., 1995), we obtain:

$$log(y_t) - log(y_{t-1}) = g + \left(1 - e^{-(1-\alpha-\gamma)(\delta+g+n)}\right)\Big(\beta_1 log(s_k) + \beta_2 log(s_h) - \beta_3 log(\delta + g + n) - log(y_{t-1}) + \frac{1}{1-\alpha-\gamma} log(\phi) - log(A) - gt\Big) \quad (13)$$

This simplifies to:

$$log(y_t) - log(y_{t-1}) = \xi + \beta_0 log(y_{t-1}) + \beta_1 log(s_k) + \beta_2 log(s_h) + \beta_3 log(\delta + g + n) + \varepsilon \quad (14)$$

Following Shan et al (2014),who uses economic growth rates (y') to avoid spurious regression rather than the level of output (y), this study substitute the left-hand side with the growth rate. This yields the conditional β convergence model:

$$y' = \xi + \beta_0 log(y_{t-1}) + \beta_1 log(s_k) + \beta_2 log(s_h) + \beta_3 log(\delta + g + n) + \varepsilon \quad (15)$$

Given that this study focuses on Chinese prefecture-level cities within a single country, a constant and identical depreciation rate at the national level is assumed. The constant term $(\delta + g + n)$ is absorbed into the error term. The model simplifies to:

$$y' = \xi + \beta_0 log(y_{t-1}) + \beta_1 log(s_k) + \beta_2 log(s_h) + \varepsilon \quad (16)$$

This formula, derived from the Solow Model, also known as β convergence, plays a pivotal role in explaining regional economic disparities.

3.2 Theoretical Framework

Building upon the theoretical foundations of NEG theory and NGT, this study develops an integrated analytical framework to disentangle the multidimensional mechanisms through which HSR infrastructure reshapes regional economic disparities, as shown in Figure 1. The development of the HSR network may exert significant impacts on regional accessibility and connectivity, thereby reducing barriers to the mobility of economic factors. This infrastructure enhancement facilitates the cross-regional flow of technology, knowledge, capital, labor, and other endogenous productive elements, consequently leading to both agglomeration effects and spatial spillover effects.

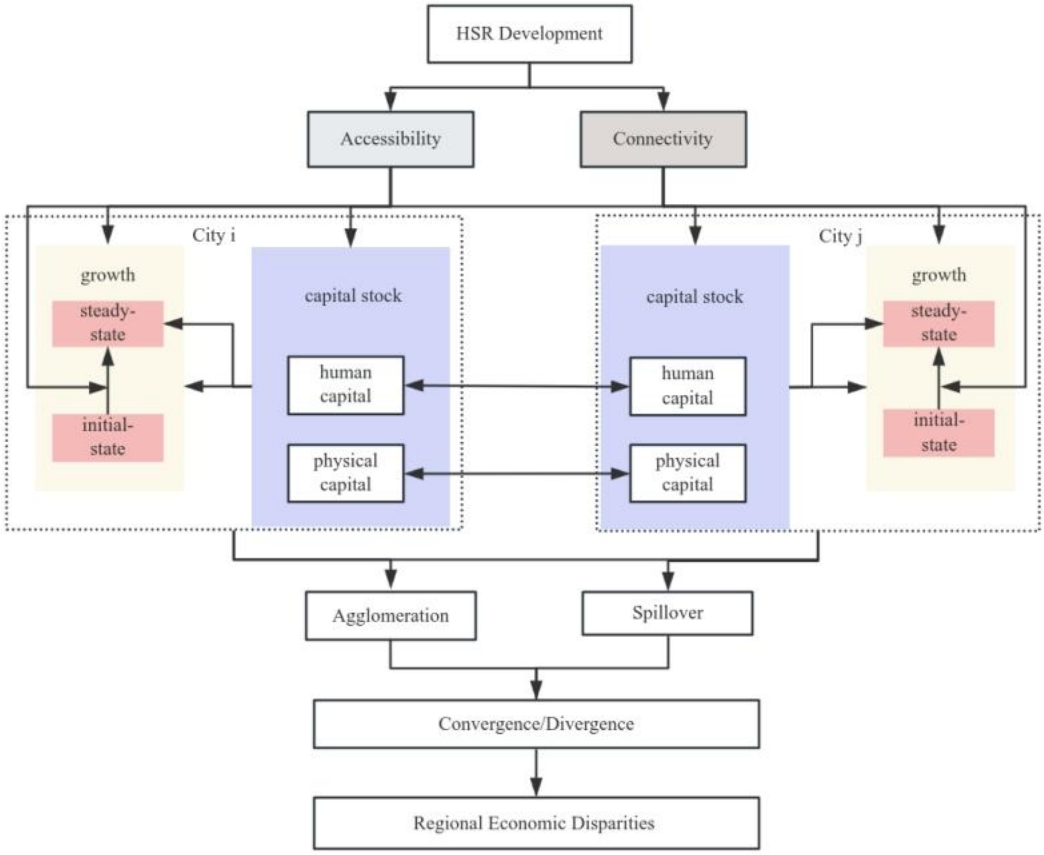


Fig.1 Theoretical Framework

4. Methodology and data

4.1 Empirical model

This section outlines the empirical models designed to test the conditional β convergence hypothesis and, crucially, to uncover its implications under HSR for regional disparities in China. Model complexities are progressively introduced to capture key drivers of HSR and spatial inter-dependencies affecting this convergence-inequality nexus. In total mechanics examined by the empirical model can be shown as Fig.2.

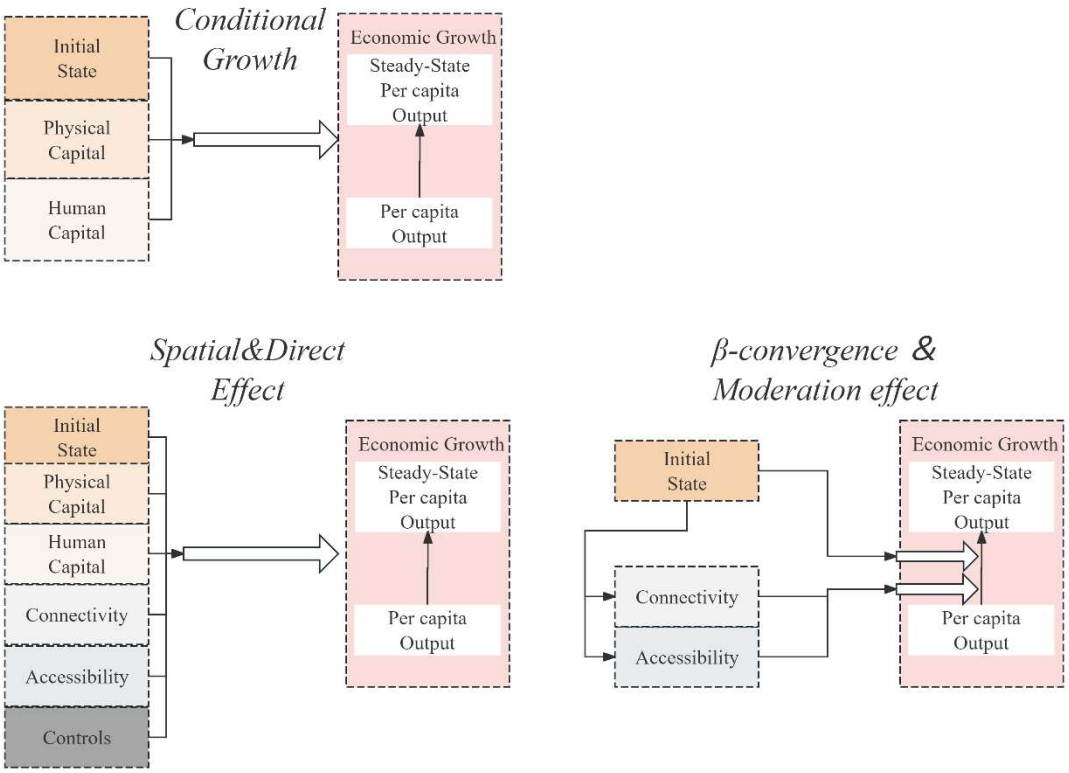


Fig.2 Empirical model

Building upon the Solow Model, this foundational baseline model estimates the basic speed of conditional convergence and its inherent inequality implication:

$$y_{i,t}' = \xi + \beta_0 log(y_{i,t-1}) + \beta_1 log(s_k) + \beta_2 log(s_h) + \mu_i + \lambda_t + \varepsilon_{i,t} \quad (17)$$

$y_{i,t}'$: Growth rate of GDP per capita for region i in period t.

$log(y_{i,t-1})$: The logarithm with ten as the base of the initial level of GDP per capita for region i at time $t-1$.

β_0: Convergence Coefficient: A statistically significant negative β_0 ($\beta_0 < 0$) provides evidence for conditional convergence. Its magnitude ($|\beta_0|$) directly determines the speed at which regions close the gap towards their respective steady states. A larger $|\beta_0|$implies faster convergence and thus potentially faster reduction in conditional inequality.

$log(s_k)$, $log(s_h)$: The logarithm with ten as the base of the vector of saving rates of physical capital and saving rates of human capital, representing factors determining region i's steady-state level of development. The coefficients β_1, β_2 indicate how these factors influence the long-run equilibrium. Crucially, differences in these variables across regions imply different steady states, meaning convergence occurs only towards these region-specific levels, not towards absolute equality. Persistent inequality is fundamentally driven by persistent differences in steady-state determinants.

μ_i: Region fixed effects, capturing unobserved, time-invariant factors influencing a region's steady-state level. These fixed effects themselves represent a source of persistent inequality.

λ_t: Time fixed effects, controlling for common macroeconomic shocks or trends affecting all regions equally within a period.

$\varepsilon_{i,t}$: Idiosyncratic error term.

To obtain a more precise and robust estimate of the convergence speed β and to better identify the impact causing by HSR on long-run inequality, this study augments the baseline model with ACC and CON representing accessibility and connectivity induced by HSR and other additional relevant determinants of the steady state:

$$y_{i,t}' = \xi + \beta_0 log(y_{i,t-1}) + \beta_1 log(s_k) + \beta_2 log(s_h) + \beta_{ACC} \times ACC + \beta_{CON} \times CON + \gamma \times Controls + \mu_i + \lambda_t + \varepsilon_{i,t} \quad (18)$$

ACC, CON: Accessibility and Connectivity brought by HSR. ACC represents the average daily train frequency servicing city i. CON denotes the normalized degree

centrality of city i (e.g., if city i connects to n cities and the total number of prefecture-level cities in China is m, then $CON = {}^{n}/_{m}$). The logarithm with ten as the base is applied to both ACC and CON for model inclusion.

$Controls$: An augmented vector of control variables beyond s_k and s_h, incorporating additional factors theorized to influence a region's long-run development path and growth potential.:

Recognizing that regional economies are interconnected, Spatial Durbin β convergence model incorporates spatial dependencies, which makes it possible to examine how a region's growth and convergence are influenced not only by its own characteristics but also by those of its neighbors, fundamentally altering the inequality dynamics:

$$y_{i,t}{}' = \xi + \rho y_{i,t}{}' + \beta_0 log(y_{i,t-1}) + \beta_1 log(s_k) + \beta_2 log(s_h) + \beta_{ACC} \times ACC + \beta_{CON} \times CON + \gamma \times Controls + \beta_{w0} log(y_{t-1}) * W_x + \beta_{w1} log(s_k) * W_x + \beta_{w2} log(s_h) * W_x + \beta_{wACC} \times ACC * W_x + \beta_{wCON} \times CON * W_x + \gamma_w \times Controls * W_x + \mu_i + \lambda_t + \varepsilon_{i,t} \quad (19)$$

W_x: A geographical distance-weighted matrix. Following established practice, an inverse-squared distance matrix is adopted.

ρ: Spatial Auto regressive Coefficient. A significant $\rho \neq 0$ indicates the presence of growth spillovers. $\rho > 0$ suggests positive spillovers (neighbors' growth boosts local growth), potentially fostering regional clusters and reducing inequality within cluster. $\rho < 0$ suggests negative spillovers (e.g., competition, congestion), potentially exacerbating divergence.

β_{w0}: Coefficient on Spatially Lagged Initial GDP per capita. This captures how

neighbors' initial development levels affect local convergence. $\beta_{w0} < 0$ suggests a region surrounded by initially richer neighbors converges slower (negative neighborhood effect). $\beta_{w0} > 0$ suggests catching-up process is faster if neighbors are richer.

β_{wn}: Coefficients on Spatially Lagged Independent Variables. These capture cross-region spillover effects: how neighbors' characteristics impact the local region's growth. This is critical for understanding how policy or investment in one region might indirectly affect inequality in neighboring regions.

Building upon the conditional convergence framework, this study investigates whether HSR moderates the fundamental convergence process itself. This is crucial for understanding heterogeneity in convergence speeds across regions and identifying potential mechanisms to accelerate the catching-up process of lagging regions. The moderation model introduces interaction terms involving a moderator variable.

$$y_{i,t}' = \xi + \beta_0 log(y_{i,t-1}) + \beta_{0A} log(y_{i,t-1} * ACC) + \beta_{0C} log(y_{i,t-1} * CON) + \beta_1 log(s_k) + \beta_2 log(s_h) + \beta_{ACC} \times ACC + \beta_{CON} \times CON + \gamma \times Controls + \mu_i + \lambda_t + \varepsilon_{i,t} \quad (20)$$

$y_{i,t-1} * ACC, y_{i,t-1} * CON$: Interaction term between city i's initial GDP per capita $y_{i,t-1}$and HSR metrics (ACC,CON), where two moderating variables (t_1 and t_2) are used to separately agent $y_{i,t-1} * ACC$ and $y_{i,t-1} * CON$. t_1 represents convergence speed impacted by ACC and t_2 represents convergence speed impacted by CON.

β_{0A}, β_{0C}: Coefficient of the interaction term. Its magnitude and sign reveal *HSR*'s effect on the speed of convergence interpretation: The coefficient β_{0A}, β_{0C} measure

how ACC and CON alter the convergence speed: A negative coefficient implies HSR accelerates convergence (reducing regional disparities). A positive coefficient implies HSR impedes convergence (potentially exacerbating disparities).

All these models above are established aiming to comprehensively capture the dynamic convergence of regional inequality under the effect of HSR. Firstly, the baseline model provides the initial estimate of the β_0 coefficient, indicating whether there's a systematic tendency for initially poorer regions to grow faster after controlling for their steady-state determinants and fixed characteristics. Secondly, the Conditional and Spatial Durbin β convergence model are used to capture the HSR's direct and spatial impact on inequality and disentangle the precise mechanisms through which HSR influences regional inequality. Finally, the moderation model aims to examine what are the association between HSR and convergence speed.

4.2 Variables and data

In the context of HSR operationalization, various methodological approaches have been adopted in the literature. E.g., Jia et al. (2017)., measured accessibility through daily commuting frequency, while S. Liu et al. (2020)., assessed connectivity using degree centrality weighted by HSR service quality. Besides, M. Liu et al. (2023)., Ou et al. (2025)., and D. Shi et al. (2025)., have applied a Difference-in-Differences (DID) framework, indicating the inauguration of HSR services as the primary measure by using a binary variable. Building on these methodological foundations, the existing literatures adopt daily train frequency to represent accessibility (ACC) and employs degree

centrality to capture connectivity (CON). The variable selection, informed by prior research, is summarized in Table 1.

Table 1. Data description and sources

Variables	Description	Calculation	Sources
y'	The growth rate of GDP per capita	$grdp/grdp_{t-1}$	China City Statistical Yearbook
$grdp$	Actual GDP per capita of cities	GDP/population	China City Statistical Yearbook
s_k	fraction of income invested in physical capital	Self-raised Funds in Fixed-Asset Investment/GDP	China Statistical Yearbook
s_h	fraction of income invested in human capital	Students/population	China City Statistical Yearbook
ACC	Accessibility caused by HSR	HSR's daily service frequency	Official Railway Timetables
CON	Connectivity caused by HSR	City's degree centrality in the HSR network	Official Railway Timetables
GOV	Government Scale	Log of Revenue of the Government	China City Statistical Yearbook
SEC	Industrial Upgrading Level	Output of the sec industry/Total output	China City Statistical Yearbook
INO	Innovation degree	China Regional Innovation and Entrepreneurship Index	Peking University Enterprise Big Data Research Center
$road$	Road Infrastructure Density	Road density	China Transport Yearbook

Following M. Liu et al (2023)'s work, this study categorizes Chinese cities into core and non-core groups. All empirical specifications are estimated using three distinct samples, the full sample, core cities, and non-core cities, to account for potential heterogeneity across city tiers.

5. Result

This section presents the empirical findings, which include the following: (1) The spatial Durbin model (SDM) for β-convergence is used to identify the direct and spatial spillover effects of HSR on convergence; (2) Moderation analyses are conducted to test the interaction effects between HSR and convergence speed. All analyses were performed separately for the full sample, core cities, and non-core cities to capture potential heterogeneity. The baseline empirical results and robustness tests are presented in the appendix.

5.1 Main Result

The regression analysis is illustrated in Table 2 and Fig.3, showing the direct and spatial spillover effects of HSR on regional economic convergence. Firstly, accessibility exhibits a significantly negative direct effect ($\beta_{ACC} = -0.00803, p < 0.01$) and a positive spatial spillover effect ($\beta_{wACC} = 0.0149, p < 0.01$), indicating that it contributes to narrowing regional disparities both directly and through spatial channels. In contrast, connectivity is not statistically significant. Secondly, the strength of convergence, reflected by the direct effect of initial $grdp$, shows negative and significant ($\beta_0 = -0.386, p < 0.01$), and a significant positive spatial spillover is observed ($\beta_{w0} = 0.311, p < 0.01$), suggesting a convergent trend of the regional economy. Finally, s_k exerts a negative influence, implying that HSR may help decouple capital accumulation from regional inequality, while s_h displays a positive effect as anticipated.

Table 2 Result of the SDM convergence model

	Full sample		Core-cities		Non-core cities	
	Direct	Spatial	Direct	Spatial	Direct	Spatial
$grdp$	-0.386***	0.311***	-0.472***	0.257***	-0.366***	0.305***
	(0.0128)	(0.0286)	(0.0384)	(0.0781)	(0.0130)	(0.0288)
s_k	-0.0317*	0.000190	-0.0341	0.0764	-0.0234	-0.0124
	(0.0168)	(0.0272)	(0.0227)	(0.0515)	(0.0187)	(0.0294)
s_h	0.0173***	0.00962	0.104***	-0.128	0.0101*	0.0187
	(0.00565)	(0.0192)	(0.0321)	(0.0885)	(0.00554)	(0.0177)
ACC	-0.00803***	0.0149***	0.000721	-0.00917	-0.00998**	0.0157*
	(0.00240)	(0.00563)	(0.00361)	(0.00766)	(0.00411)	(0.00829)
CON	0.000398	0.00171	0.000747	0.0192**	0.00161	-0.00203
	(0.00217)	(0.00653)	(0.00434)	(0.00896)	(0.00239)	(0.00731)
GOV	0.0953***	-0.0686***	0.202***	-0.0135	0.0956***	-0.0814***
	(0.00897)	(0.0193)	(0.0285)	(0.0507)	(0.00912)	(0.0195)
SEC	0.00625***	-0.00413***	0.00387***	-0.00544**	0.00623***	-0.00385***
	(0.000393)	(0.000822)	(0.00135)	(0.00236)	(0.000395)	(0.000802)
INO	0.000372*	0.000771	-0.00257*	-0.00201	0.000399*	0.000698
	(0.000225)	(0.000611)	(0.00135)	(0.00380)	(0.000229)	(0.000579)
$road$	-0.000502	0.00286*	0.00125	-0.00485	-0.000645*	0.00351**
	(0.000391)	(0.00148)	(0.00149)	(0.00423)	(0.000390)	(0.00148)
ρ	0.879***		0.621***		0.879***	
	(0.0205)		(0.0493)		(0.0201)	
σ^2	0.00456***		0.00421***		0.00420***	
	(0.000111)		(0.000293)		(0.000110)	
Obs	3,444		432		3,012	
R-squared	0.142		0.102		0.146	
Number of id	287		36		251	

Note: *, **, and *** indicate passing significance tests at the 10%, 5%, and 1% levels, respectively, with t-statistics in parentheses.

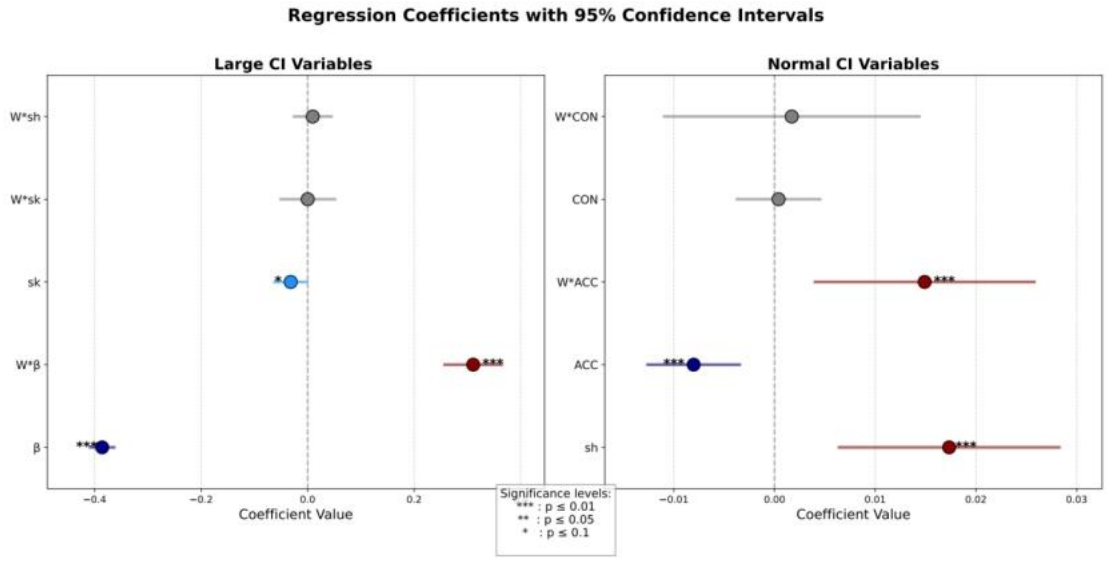


Fig. 3. Regression coefficients of the full sample

Fig. 4 and Fig. 5 present the heterogeneous effects of HSR between core and non-core cities. Connectivity in core cities shows a significant positive indirect effect ($\beta_{wCON} = 0.0192, p < 0.05$), though its direct effect is not significant, while accessibility exhibits no significant direct or indirect effects. Initial $grdp$ maintains a significant negative direct effect ($\beta_0 = -0.472, p < 0.01$) and generates a significant positive spatial effect ($\beta_{w0} = 0.257, p < 0.01$), confirming the existence of convergence. In non-core cities, effects cities present a different picture. Accessibility shows a significantly negative direct effect ($\beta_{ACC} = -0.00998, p < 0.05$) and a positive spatial effect at the 10% significance level ($\beta_{wACC} = 0.0157, p < 0.10$). The initial $grdp$ also exhibits a significantly negative direct effect ($\beta_0 = -0.366, p < 0.01$) and a positive indirect effect ($\beta_{w0} = 0.305, p < 0.01$), which suggests that the convergence trend in non-core cities is less pronounced than in core cities.

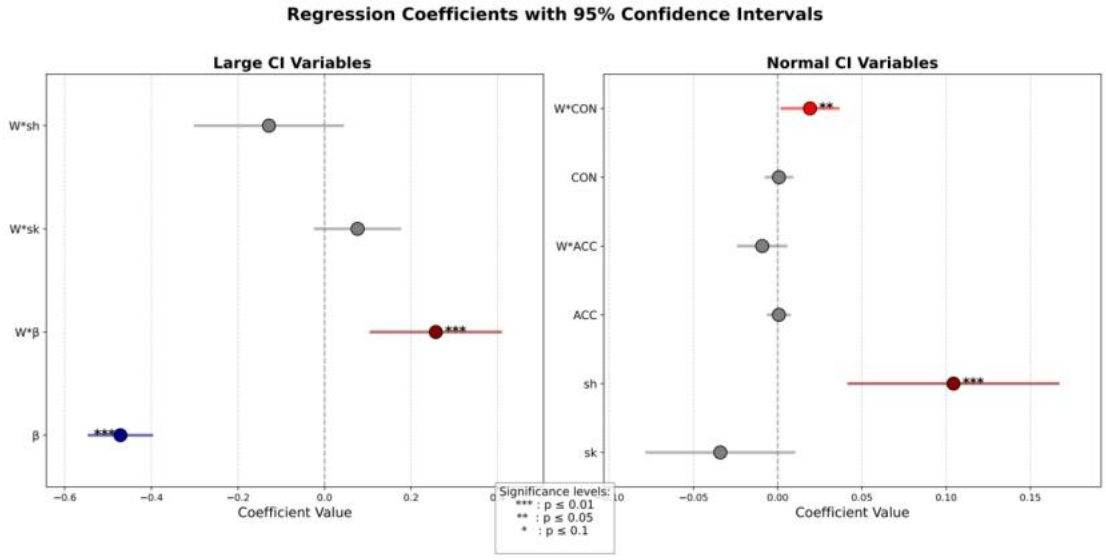


Fig. 4. Regression coefficients of core cities

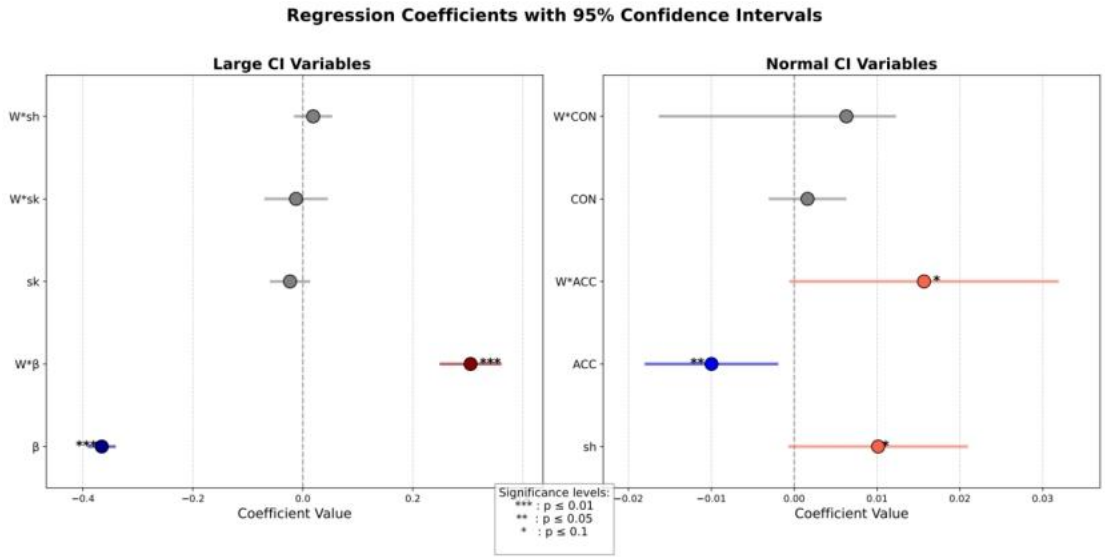


Fig. 5. Regression coefficients of non-core cities

5.2 Moderation Result

Table 3 shows the convergence speed moderated by accessibility and connectivity. A moderating model is used to describe the convergence. t_1 has a significantly negative impact ($\beta_{0A} = -0.0346, p < 0.01$), which means accessibility can accelerate the speed of convergence. Meanwhile, t_2 shows a negative and significant effect ($\beta_{0C} = -0.000820, p < 0.05$). Notably unlike its moderating effect, accessibility's direct effect is positive and significant ($\beta_{ACC} = 0.0308, p < 0.01$), while the direct effect of connectivity is statistically insignificant in both models.

Table 3 Result of the moderation model

VARIABLES	Full sample	Core-cities	Non-core cities
$grdp$	-0.363***	-0.424***	-0.349***
	(0.0126)	(0.0378)	(0.0131)
t_1	-0.0346***	-0.0166**	-0.0454***
	(0.00436)	(0.00739)	(0.00564)
t_2	-0.00820**	-0.0261***	-0.00768*
	(0.00351)	(0.00903)	(0.00405)
s_k	-0.0364***	-0.0302	-0.0343***
	(0.0117)	(0.0243)	(0.0126)
s_h	0.0240***	0.102***	0.0188***

	(0.00676)	(0.0352)	(0.00667)
ACC	0.0308***	0.0209**	0.0261***
	(0.00547)	(0.00983)	(0.00621)
CON	-0.00388	0.00754	-0.00492*
	(0.00249)	(0.00545)	(0.00297)
GOV	0.145***	0.212***	0.138***
	(0.00931)	(0.0302)	(0.00942)
SEC	0.00632***	0.00382***	0.00670***
	(0.000434)	(0.00147)	(0.000442)
INO	0.000498*	-0.00351**	0.000405
	(0.000267)	(0.00139)	(0.000274)
$road$	-5.96e-05	0.000900	-0.000324
	(0.000467)	(0.00158)	(0.000469)
Constant	1.590***	1.887***	1.520***
	(0.139)	(0.459)	(0.142)
Obs	3,444	432	3,012
Number of id	287	36	251
R^2	0.410	0.631	0.442

Note: *, **, and *** indicate passing significance tests at the 10%, 5%, and 1% levels, respectively, with t-statistics in parentheses.

The results towards the core cities indicates that t_1 has a weaker negative and significant effect ($\beta_{0A} = -0.0166, p < 0.05$). Meanwhile, comparing to the full sample, t_2 shows a stronger negative effect significantly ($\beta_{0C} = -0.0561, p < 0.01$). Similar to the effect for the full sample, accessibility's direct effect is positive and significant ($\beta_{ACC} = 0.0209, p < 0.05$). For non-core cities, the effect of t_1 is stronger than core cities, emerging negative and significant ($\beta_{0A} = -0.0454, p < 0.05$), and t_2's effect remains negative and significant but weaker ($\beta_{0C} = -0.00768, p < 0.10$). Considering the direct effect, accessibility exhibits a positive effect significantly ($\beta_{ACC} = 0.0261, p < 0.01$), while notably, connectivity's direct effects establish negative and significant ($\beta_{CON} = -0.00492, p < 0.10$).

6. Discussion

6.1 **Direct Effects**

The direct effects of HSR can be explained by its profound alterations in the flow patterns of production factors, i.e., physical capital and labor. Jin & Zhu (2023) demonstrate that HSR could increase the similarity of industrial structures, and Yan et al. (2022) state that HSR could promote labor force restructuring. While M. Liu et al. (2023) argue for an agglomerative flow of physical capital and use venture capital investment as a proxy, one that potentially captures only specific types of capital, which may explain the discrepancy between their findings and this study, as the latter focuses on broader capital mobility facilitated by HSR connectivity. However, this study elucidates that HSR could enhance the exchange of resources, thereby facilitating the flow of physical capital from more developed cities to less developed ones. Concurrently, regarding human capital, this study also indicates that HSR significantly amplifies its agglomeration in core cities, underscoring HSR's role in intensifying human capital flows toward central nodes in the urban network. In addition, there is a vital interesting flip of the coefficient of s_k between the baseline (Table B.1, where it is positive) and the spatial model (Table 2). The change of s_k may be explained by the fact that, in the baseline model, the contribution of physical capital savings to growth could be subject to omitted variable bias. After controlling for HSR connectivity, transportation infrastructure, industrial upgrading, and innovation indices, the positive effect of capital accumulation is absorbed by these covariates. Once infrastructure, such as the HSR network, reaches a certain threshold, further increases in physical capital savings may inhibit growth if such capital fails to flow into high-value-added sectors.

Furthermore, these direct effects exhibit notable heterogeneity across the different types of cities. For non-core cities, the positive inflow of physical capital is particularly pronounced, serving as a crucial mechanism for their "catching-up" process. In contrast, for core cities, the direct effect of HSR is more evident in the significant positive agglomeration of human capital. Importantly, such an agglomeration effect alters the non-significant influence of s_h observed in the baseline model and optimizes the labor force structure of these economic centers.

6.2 Spatial Spillover Effects

Existing literature stated that the spatial effects of HSR can constitute an important driver for promoting regional balance, demonstrating the significant spatial asymmetry. From the lens of economic activity, Zheng et al. (2019) find that HSR increased nighttime light intensity in surrounding areas by an average of 27% through the spillover effect. And in terms of urban economic resilience, R. Li et al. (2023) discover that HSR enhances the economic resilience of neighboring cities by promoting the level of innovation, while K. Shi & Wang (2024) demonstrate its role in promoting infrastructure upgrades in adjacent areas. Consistent with these findings, this research confirms the mechanism underlying these observed phenomena as the presence of robust positive spatial spillover effects in promoting growth. Collectively, these findings corroborate the "borrowed size" development mechanism identified in this study. Specifically, HSR can generate tangible developmental dividends for less developed neighboring cities through the spillover of knowledge, technology, and resources, thereby forming the pathway of its spatial effects.

In addition, the dominant pathways of these spatial effects exhibit clear heterogeneity across city hierarchies. As core cities primarily exert radiative and driving influences within regions through their powerful connectivity, facilitating the outward spillover of technology and knowledge. While non-core cities, conversely, act predominantly as beneficiaries, more effectively receiving these positive spillovers from their "richer neighbors" due to enhanced accessibility. This differential interaction ultimately serves to narrow the regional development gap.

6.3 Moderating Effects

The equality-promoting effect of HSR is not linear but dually moderated by both the regional development level and city type. Specifically, HSR significantly accelerates economic development at low development levels. However, as development level and accessibility increase, such an effect undergoes a transition, slowing absolute growth while simultaneously promoting regional convergence and equality. Regarding the development level, this study identifies a significant "threshold effect" in HSR's equality-promoting role. This finding resonates with the Ke et al. (2017) and Liang et al. (2020)'s work, which emphasize the close relationship between HSR's impact and a city's inherent development level. Furthermore, this research confirms and refines the specific manifestations of this non-linear relationship by employing a moderating effects model. More precisely, the equality-promoting effect of HSR exhibits a significant development threshold effect. While accessibility might initially promote growth and exacerbate inequality in cities with low GDP per capita, once a certain development

level is surpassed, its role shifts towards fostering convergence. Similarly, the moderating effect of connectivity on convergence is most potent when coupled with high development levels in cities.

Beyond development level, the city type itself acts as a key structural moderating variable. Economic convergence in core cities is more sensitive to changes in connectivity, whereas the catching-up process in non-core cities relies more heavily on improvements in accessibility. This structural distinction explains the underlying reasons for the differentiated outcomes of HSR policies across different regions. In this context, the conclusion in this study regarding the regional heterogeneity of HSR effects is consistent with Jiao et al. (2017), who find that core cities are primarily influenced by connectivity, whereas non-core cities are more sensitive to accessibility.

7. Conclusion

This study identifies distinct direct drivers shaping regional imbalance, revealing significant variations between core and non-core cities in China, as well as complex interactions with their economic development levels. (1) From the perspective of direct effect, HSR contributes to equality by fostering the dispersion of physical capital from developed cities to others, facilitating their catch-up. (2) As to the spatial spillover effect, HSR generates positive spillovers, enabling a “borrowed size” mechanism for developing cities through enhanced accessibility. (3) When considering its moderating effect, the role of HSR evolves from initially promoting regional growth while exacerbating disparities to eventually slowing growth and accelerating convergence after a

certain economic level is attained. These findings underscore that HSR's ultimate impact on regional equality is not uniform but is fundamentally shaped by the specific spatial context and developmental stage of the cities involved.

The empirical findings of this study indicate that high-speed rail (HSR) networks have generally fostered regional economic convergence. This result aligns with the neoclassical growth theory, which posits that improved transportation can help narrow regional disparities. However, this does not imply that the insights of New Economic Geography (NEG) regarding increasing returns to scale and agglomeration mechanisms are invalid. On the contrary, these findings call for a more nuanced and conditional interpretation of NEG models.

This study argue that, within China's current development stage and under its strong regional coordination policies, the market-access effects and knowledge-diffusion effects brought about by HSR have outweighed its pure siphoning effect on production factors. HSR has facilitated more efficient industrial spillovers and technology diffusion from core cities, leading to the emergence of a new agglomeration-convergence pattern at the scale of metropolitan areas or city clusters. In this pattern, core cities act as growth poles, while surrounding areas experience synergistic development. This supports the "dispersion phase" anticipated by NEG theory when transport costs fall beyond a critical threshold, and underscores the crucial role of institutions and policies in shaping economic geography.

This study introduces a novel theoretical perspective on the economic implications of HSR, moving beyond conventional narratives centered solely on economic growth

and regional inequality. A key theoretical contribution of this study lies in its development of a Solow Model-based metric for inequality, which integrates elements from both the NGT and NEG theory to capture how HSR-induced "accessibility" and "connectivity" collectively shape economic disparities. By explicitly tracing the pathways through which transportation infrastructure influences regional development, this research offers a refined conceptual framework for understanding the mechanisms behind spatial economic variation. Furthermore, the analytical approach adopted here is generalizable to other forms of transportation infrastructure, i.e., seaports, airports, and highways, which similarly affect accessibility and connectivity across regions. Thus, this study provides a broader theoretical foundation for assessing how transportation infrastructures impact economic divergence, highlighting the critical importance of impact pathways in spatial economic analysis.

The differential effects of "accessibility" and "connectivity" suggest that HSR expansion should be integrated into broader regional development strategies. Policies aimed at reducing interregional inequality should prioritize enhancing accessibility in non-core cities to facilitate positive spillovers of capital, labor, and knowledge from more developed regions. While connectivity enhancements can be strategically used to support sustainable growth in core cities through "borrowed size" effects. Governments should encourage cooperation between cities to maximize net benefits and ensure that resource redistribution does not undermine overall economic performance.

Although this study possesses panel data at the prefecture-level city level, cross-sectional regression was deemed inappropriate to mitigate endogeneity concerns at the

city level. Consequently, panel regression methods were employed, though this approach limited the ability to capture the effects of HSR at a more granular temporal scale. Furthermore, municipal statistical yearbooks do not provide a direct proxy for the physical capital investment rate (s_k), as data on fixed-asset investment at the prefecture level include components such as loans, which do not align with the definition of s_k in the Solow Model. Therefore, s_k was proxied using the provincial-level ratio of self-raised funds to total output.

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REFERENCE

Cascetta, E., Cartenì, A., Henke, I., & Pagliara, F. (2020). Economic growth, transport accessibility and regional equity impacts of high-speed railways in Italy: Ten years ex post evaluation and future perspectives. *Transportation Research Part A: Policy and Practice*, *139*, 412–428. https://doi.org/10.1016/j.tra.2020.07.008

Chen, C.-L., & Vickerman, R. (2017). Can transport infrastructure change regions' economic fortunes? Some evidence from Europe and China. *Regional Studies*, *51*(1), 144–160. https://doi.org/10.1080/00343404.2016.1262017

Chen, Z., & Haynes, K. E. (2017). Impact of high-speed rail on regional economic disparity in China. *Journal of Transport Geography*, *65*, 80–91. https://doi.org/10.1016/j.jtrangeo.2017.08.003

Cheng, Y., Loo, B. P. Y., & Vickerman, R. (2015). High-speed rail networks, economic integration and regional specialisation in China and Europe. *Travel Behaviour and Society*, *2*(1), 1–14. https://doi.org/10.1016/j.tbs.2014.07.002

Di Matteo, D., & Cardinale, B. (2023). Impact of high-speed rail on income inequalities in Italy. *Journal of Transport Geography,*, *111*, 103652. https://doi.org/10.1016/j.jtrangeo.2023.103652

Dong, X., Zheng, S., & Kahn, M. E. (2020). The role of transportation speed in facilitating high skilled teamwork across cities. *Journal of Urban Economics*, *115*, 103212. https://doi.org/10.1016/j.jue.2019.103212

Duan, L., Niu, D., Sun, W., & Zheng, S. (2021). Transportation infrastructure and capital mobility: Evidence from China's high-speed railways. *The Annals of Regional Science*, *67*(3), 617–648. https://doi.org/10.1007/s00168-021-01059-w

Fan, X., & Xu, Y. (2023). Does high-speed railway promote urban innovation? Evidence from China.

Socio-Economic Planning Sciences, *86*, 101464. https://doi.org/10.1016/j.seps.2022.101464

Jia, S., Zhou, C., & Qin, C. (2017). No difference in effect of high-speed rail on regional economic growth based on match effect perspective? *Transportation Research Part A: Policy and Practice*, *106*, 144–157. https://doi.org/10.1016/j.tra.2017.08.011

Jiao, J., Wang, J., & Jin, F. (2017). Impacts of high-speed rail lines on the city network in China. *Journal of Transport Geography*, *60*, 257–266. https://doi.org/10.1016/j.jtrangeo.2017.03.010

Jin, W., & Zhu, S. (2023). High-speed rail network and regional convergence/divergence in industrial structure. *Socio-Economic Planning Sciences*, *87*, 101546. https://doi.org/10.1016/j.seps.2023.101546

Ke, X., Chen, H., Hong, Y., & Hsiao, C. (2017). Do China's high-speed-rail projects promote local economy?—New evidence from a panel data approach. *China Economic Review*, *44*, 203–226. https://doi.org/10.1016/j.chieco.2017.02.008

Kong, Q., Li, R., Jiang, X., Sun, P., & Peng, D. (2022). Has transportation infrastructure development improved the quality of economic growth in China's cities? A quasi-natural experiment based on the introduction of high-speed rail. *Research in International Business and Finance*, *62*, 101726. https://doi.org/10.1016/j.ribaf.2022.101726

Krugman, P. (1991). Increasing Returns and Economic Geography. *The Journal of Political Economy*, *99*(3), 483–499.

Li, R., Xu, M., & Zhou, H. (2023). Impact of high-speed rail operation on urban economic resilience: Evidence from local and spillover perspectives in China. *Cities*, *141*, 104498. https://doi.org/10.1016/j.cities.2023.104498

Li, X., Huang, B., Li, R., & Zhang, Y. (2016). Exploring the impact of high speed railways on the spatial redistribution of economic activities—Yangtze River Delta urban agglomeration as a case study. *Journal of Transport Geography*.

Li, Y., Chen, Z., & Wang, P. (2020). Impact of high-speed rail on urban economic efficiency in China. *Transport Policy*, *97*, 220–231. https://doi.org/10.1016/j.tranpol.2020.08.001

Liang, Y., Zhou, K., Li, X., Zhou, Z., Sun, W., & Zeng, J. (2020). Effectiveness of high-speed railway on regional economic growth for less developed areas. *Journal of Transport Geography*, *82*, 102621. https://doi.org/10.1016/j.jtrangeo.2019.102621

Liu, L., & Zhang, M. (2018). High-speed rail impacts on travel times, accessibility, and economic productivity: A benchmarking analysis in city-cluster regions of China. *Journal of Transport Geography*, *73*, 25–40. https://doi.org/10.1016/j.jtrangeo.2018.09.013

Liu, M., Jiang, Y., Wei, X., Ruan, Q., & Lv, D. (2023). Effect of high-speed rail on entrepreneurial activities: Evidence from China. *Socio-Economic Planning Sciences*, *87*, 101538. https://doi.org/10.1016/j.seps.2023.101538

Liu, S., Wan, Y., & Zhang, A. (2020). Does China's high-speed rail development lead to regional disparities? A network perspective. *Transportation Research Part A: Policy and Practice*, *138*, 299–321. https://doi.org/10.1016/j.tra.2020.06.010

Mankiw, N. G., Romer, D., & Weil, D. N. (1992). A Contribution to the Empirics of Economic Growth*. *The Quarterly Journal of Economics*, *107*(2), 407–437. https://doi.org/10.2307/2118477

Ou, Y., Zheng, J., Li, S., Chen, K., & Bao, Z. (2025). High-speed rail development and economic per-

formance: A perspective on urban-rural disparities in the treatment and spillover effects. *Research in Transportation Business & Management*, *59*, 101287. https://doi.org/10.1016/j.rtbm.2025.101287

Shan, J., Yu, M., & Lee, C.-Y. (2014). An empirical investigation of the seaport's economic impact: Evidence from major ports in China. *Transportation Research Part E: Logistics and Transportation Review*, *69*, 41–53. https://doi.org/10.1016/j.tre.2014.05.010

Shi, D., Wang, L., Zhang, X., & Yu, T. (2025). Borrowed size and borrowed administrative power: Effects of high-speed rail network on industrial upgrading and variegated externalities in the Yangtze River Delta, China. *Journal of Transport Geography*, *123*, 104113. https://doi.org/10.1016/j.jtrangeo.2025.104113

Shi, K., & Wang, J. (2024). The influence and spatial effects of high-speed railway construction on urban industrial upgrading: Based on an industrial transfer perspective. *Socio-Economic Planning Sciences*, *93*, 101886. https://doi.org/10.1016/j.seps.2024.101886

Solow, R. M. (1956). A Contribution to the Theory of Economic Growth. *The Quarterly Journal of Economics*, *70*(1), 65–94. https://doi.org/10.2307/1884513

Tian, M., Wang, Yiwei, & Wang, Yiran. (2023). High-speed rail network and urban agglomeration economies: Research from the perspective of urban network externalities. *Socio-Economic Planning Sciences*, *85*, 101442. https://doi.org/10.1016/j.seps.2022.101442

Wang, C., Chen, J., Li, B., Chen, N., & Wang, W. (2023). Impact of high-speed railway construction on spatial patterns of regional economic development along the route: A case study of the Shanghai–Kunming high-speed railway. *Socio-Economic Planning Sciences*, *87*, 101583. https://doi.org/10.1016/j.seps.2023.101583

Wang, F., Liu, Z., Xue, P., & Dang, A. (2022). High-speed railway development and its impact on urban economy and population: A case study of nine provinces along the Yellow River, China. *Sustainable Cities and Society*, *87*, 104172. https://doi.org/10.1016/j.scs.2022.104172

Wang, L., Yuan, F., & Duan, X. (2018). How high-speed rail service development influenced commercial land market dynamics: A case study of Jiangsu province, China. *Journal of Transport Geography*, *72*, 248–257. https://doi.org/10.1016/j.jtrangeo.2018.09.010

Wetwitoo, J., & Kato, H. (2017). High-speed rail and regional economic productivity through agglomeration and network externality: A case study of inter-regional transportation in Japan. *Case Studies on Transport Policy*, *5*(4), 549–559. https://doi.org/10.1016/j.cstp.2017.10.008

Xiao, F. (2020). Did high-speed rail affect the entry of automobile industry start-ups? Empirical evidence from Guangdong Province, China. *Travel Behaviour and Society*.

Yan, L., Tu, M., Chagas, A. L. S., & Tai, L. (2022). The impact of high-speed railway on labor spatial misallocation—Based on spatial difference-in-differences analysis. *Transportation Research Part A: Policy and Practice*, *164*, 82–97. https://doi.org/10.1016/j.tra.2022.07.017

Yang, Z., Li, C., Jiao, J., Liu, W., & Zhang, F. (2020). On the joint impact of high-speed rail and megalopolis policy on regional economic growth in China. *Transport Policy*, *99*, 20–30. https://doi.org/10.1016/j.tranpol.2020.08.007

Yoo, S., Kumagai, J., Kawasaki, K., Hong, S., Zhang, B., Shimamura, T., & Managi, S. (2023). Double-edged trains. *Transport Policy*, *133*, 120–133. https://doi.org/10.1016/j.tranpol.2023.01.016

Yoo, S., Kumagai, J., Sho, K., & Managi, S. (2024). Impact of high-speed railway on gentrification and regional inequality in Japan. *Transportation Research Part D: Transport and Environment*,

134, 104346. https://doi.org/10.1016/j.trd.2024.104346

Zheng, L., Long, F., Chang, Z., & Ye, J. (2019). Ghost town or city of hope? The spatial spillover effects of high-speed railway stations in China. *Transport Policy*, *81*, 230–241. https://doi.org/10.1016/j.tranpol.2019.07.005

Appendix

A. Baseline β convergence

Full sample (Table B. 1, Model 1): Initial results for the full sample indicate a statistically significant negative association between initial $grdp$ and the growth speed of $grdp$ ($\beta_0 = -0.175, p < 0.01$). s_k shows a significant positive effect ($\beta_1 = 0.0279, p < 0.05$). s_h also shows a significant positive effect ($\beta_2 = 0.182, p < 0.05$).

Core cities (Table B. 1, Model 1): Disaggregating the results reveals distinct patterns. For core cities, initial $grdp$ exhibits a stronger and highly significant negative effect ($\beta_0 = -0.289, p < 0.01$). A key difference is the impact of s_k and s_h are statistically insignificant.

Non-core cities (Table B. 1, Model 1): At the same time, in non-core cities, the coefficient for initial $grdp$ is weaker negative significant ($\beta_0 = -0.150, p < 0.01$). However, s_k and s_h maintain a significant positive association ($\beta_1 = 0.0368, p < 0.05$; $\beta_2 = 0.0124, p < 0.1$).

Summary of key differences: Crucially, the effect of initial s_k and s_h diverge markedly between city types: they are significant drivers in non-core cities but lacks statistical significance in core cities. The influence of initial $grdp$, however, appears

more consistent across both groups in direction and significance.

B. Conditional β convergence

Augmented model: Model 2 builds upon Model 1 by introducing ACC, CON, and a set of control variables to account for potential confounding factors.

Full sample (Table B. 1, Model 2): Initial $grdp$ remains significant negative and stronger ($\beta_0 = -0.347, p < 0.01$), while s_k and effect changes to negative and s_h's effect stabilizes positive. The new variable ACC shows a significant negative effect ($\beta_{ACC} = -0.00699, p < 0.05$), and CON is insignificant. Key controls such as GOV, SEC, INO are also significant."

Core-cites (Table B. 1, Model 2): Focusing on core cities, the inclusion of additional variables strengthens the significant negative effect of initial $grdp$ ($\beta_0 = -0.417, p < 0.01$). s_h's impact changes to positive and significant ($\beta_2 = 0.120, p < 0.01$) ,while s_k is statistically insignificant. ACC, however, demonstrates insignificant effect, and CON remains to be insignificant.

Non-core cities (Table B. 1, Model 2): For non-core cities, the baseline finding for initial $grdp$ contribute to stronger negative significant ($\beta_0 = -0.322, p < 0.01$), and s_k as well as s_h continue to show a significant negative and positive effect ($\beta_1 = 0 - 0.0287, p < 0.05; \beta_2 = 0.0163, p < 0.05$). Notably, ACC emerges with a stronger and highly significant negative effect compared to core cities ($\beta_{ACC} = -0.0108, p < 0.01$). In contrast, CON's coefficient is statistically insignificant.

Summary of key differences: between-model differences: Between model 1and model 2, the effect of initial $grdp$ in augmented model (model 2) are stronger than

baseline model (model 1). Notably, s_h changes its significance when more variables are considered in core cities. Model 2 also reinforces the heterogeneity: s_k's insignificance is exclusive to core cities. Furthermore, ACC exerts a significantly larger impact in non-core cities, while CON's influencing role is not detectable in all groups. These findings highlight the differential importance of these factors across urban contexts.

Table B. 1 Result of model 1 and model 2

	Model 1			Model 2		
	Full sample	Core-cities	Non-core cities	Full sample	Core-cities	Non-core cities
$grdp$	-0.175***	-0.289***	-0.150***	-0.342***	-0.417***	-0.322***
	(0.0112)	(0.0346)	(0.0115)	(0.0125)	(0.0380)	(0.0128)
s_k	0.0279**	-0.00245	0.0368***	-0.0302**	-0.0231	-0.0287**
	(0.0124)	(0.0245)	(0.0134)	(0.0118)	(0.0243)	(0.0127)
s_h	0.0182**	0.0504	0.0124*	0.0237***	0.120***	0.0163**
	(0.00726)	(0.0339)	(0.00728)	(0.00683)	(0.0348)	(0.00674)
ACC				-0.00699**	0.000665	-0.0108**
				(0.00273)	(0.00383)	(0.00421)
CON				0.00202	0.000184	0.00215
				(0.00236)	(0.00436)	(0.00264)
GOV				0.144***	0.197***	0.139***
				(0.00938)	(0.0301)	(0.00950)
SEC				0.00623***	0.00392***	0.00646***
				(0.000438)	(0.00148)	(0.000445)
INO				0.000738***	-0.00267*	0.000735***
				(0.000268)	(0.00137)	(0.000273)
$road$				9.36e-05	0.00141	-0.000126
				(0.000471)	(0.00159)	(0.000473)
Constant	1.957***	3.292***	1.677***	1.360***	1.998***	1.196***
	(0.118)	(0.400)	(0.120)	(0.137)	(0.461)	(0.137)
Obs	3,444	432	3,012	3,444	432	3,012
Number of id	287	36	251	287	36	251
R^2	0.286	0.563	0.311	0.398	0.620	0.428

Note: *, **, and *** indicate passing significance tests at the 10%, 5%, and 1% levels, respectively, with t-statistics in parentheses

C. Robustness test of SDM

Table C. 1 Result of Robustness test

Test	Statistic	P-value
LM lag	832.476	0.000
LM error	2243.390	0.000
Robust LM lag	4.386	0.036
Robust LM error	1415.301	0.000
Test	Chi2(9)	Prob>Chi2
LR SAR	361.38	0.000
LR SEM	35.83	0.000
WALD SAR	60.91	0.000
WALD SEM	12.36	0.1937
Hausman	819.12	0.000