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Study on the Impact Mechanisms and Effects of High-Speed Rail Opening on Urban Consumption from a Spatial Spillover Perspective

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ABSTRACT

The reshaping effect of transportation infrastructure innovation on regional consumption patterns has become a core proposition in economic geography research. Based on panel data from 285 prefecture-level cities in China (2013–2024), this study employs a Spatial Durbin Model (SDM) to investigate the impact of high-speed rail (HSR) opening on urban consumption from a spatial spillover perspective. Using Python web scraping to collect HSR line opening information from Wikipedia and constructing an HSR opening dummy variable, combined with industrial and economic data from the CEIC database, we systematically analyze the logic of consumption spatial restructuring under time-space compression effects.

Empirical results demonstrate that HSR opening significantly promotes local consumption expansion. The fixed-effects model indicates that the total retail sales of consumer goods in HSR-opened cities increase by an average of 10.57%, with a significant positive spatial spillover ($\rho = 0.1127$). Heterogeneity analysis reveals that sub-provincial and higher-level cities amplify consumption siphon effects due to resource endowments (coefficient: 210,285.0, $p < 0.01$), while ordinary prefecture-level cities exhibit a pronounced "conduit effect" in the initial HSR phase due to weaker consumption foundations. Mechanistically, the synergy between HSR and the tertiary industry drives consumption growth in both city types, with sub-provincial cities showing stronger synergistic effects owing to advanced service industries. The HSR-export synergy forms a transmission chain through improved logistics efficiency-e.g., foreign trade consumption accounts for 28.3% in Suzhou Industrial Park. Rising housing prices exhibit a "wealth effect" in sub-provincial cities (12.70, $p < 0.01$) but a "crowding-out effect" in ordinary prefecture-level cities.

This study provides empirical support for differentiated HSR consumption policies. We recommend optimizing industrial synergy pathways and strengthening spatial equilibrium mechanisms to unlock HSR's potential for driving consumption upgrading.

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KEYWORDS: *High-speed rail; Urban consumption; Spatial spillover effects; Prefecture-level cities; Spatial Durbin Model*

1. INTRODUCTION

The innovation of transportation infrastructure has always been a core force reshaping regional economic geography and consumption patterns. Historically, iterations of major transportation facilities have profoundly rewritten the spatial form of consumption by reconstructing factor flow paths and market accessibility boundaries. In the early 19th century, the opening of the Erie Canal restructured the logistics network in the eastern United States, significantly reducing cross-regional consumer goods circulation costs and facilitating New York's rise as a national consumption hub, laying the foundation for high-end service industry agglomeration. Concurrently, the expansion of the European railway network not only

strengthened the agglomeration potential of industrial cities but also accelerated the integration of regional consumer markets by expanding the radiation radius of goods. After the founding of the People's Republic of China, the replacement of river and canal transport systems by railway construction drove hub cities like Changchun and Zhengzhou to transform from material transit nodes into comprehensive consumption centers, confirming the direct role of transportation infrastructure iteration in reshaping consumption space.

Entering the 21st century, high-speed rail (HSR), as an iconic achievement of the fourth-generation transportation revolution, breaks regional consumption time-space constraints with high speed, large capacity, and high punctuality rates, relying on technological integration such as ballast less tracks and CTCS-3 train control systems and the "Eight Vertical and Eight Horizontal" backbone network. Its time-space compression effect not only enhances the efficiency of production factor allocation but also reshapes the logic of consumption space: by expanding the radius of consumer flows, it triggers the reallocation of cross-regional demand; through the upgrading of the commercial energy level in hub cities, it promotes consumption hierarchy differentiation; and by dissolving regional market barriers, it accelerates the formation of a unified consumer market, constructing the core of consumption geographical space reconstruction.

Currently, China's HSR has built the world's largest operational network. According to CNR data, by 2025, China's HSR operating mileage reached 46,000 kilometers, covering 97.2% of cities with populations over 500,000. Its technological paradigm and operational experience have been adopted by over 40 countries globally. This signifies that HSR, as core infrastructure, deeply participates in the reshaping of global economic geography. The regional consumption spatial restructuring effects it induces provide a unique sample for analyzing the transportation-consumption interaction mechanism and exploring the evolution laws of consumption patterns. Based on this, this paper focuses on the prefecture-level city scale, employs spatial econometric methods to investigate the spillover effects of HSR opening on consumption, explores the micro-level pathways through which transportation infrastructure innovation drives consumption space optimization, and provides empirical support for improving the theory of regional consumption coordinated development and enabling the synergy between transportation and consumption policies.

Table 1-1 China's HSR Operating Mileage and Passenger Volume, 2012-2023

Indicator	2012	2013	2014	2015	2016	2017
Operating Mileage (km)	9356	11028	16456	19838	22980	25164
% of Total Railway Mileage	9.6	10.7	14.7	16.4	18.5	19.8
Passenger Volume (10,000 pax)	38815	52962	70378	96139	122128	175216
Passenger-km (100 mn pax-km)	1446	2141	2825	3863	4641	5875
Indicator	2018	2019	2020	2021	2022	2023
Operating Mileage (km)	29904	35388	37929	40139	42241	45036
% of Total Railway Mileage	22.7	25.3	25.9	26.6	27.3	28.4
Passenger Volume (10,000 pax)	205430	235833	155707	192236	127533	289788
Passenger-km (100 mn pax-km)	6871	7746	4844	6064	4386	9834

Data Source: Compiled from China Statistical Yearbook 2013-2024.

2. Literature Review

2.1. Research Context of Consumption Theory and Influencing Factors

Consumption theory research can be traced back to Keynesian theory. Subsequent scholars such as Duesenberry (1949), Modigliani (1949), and Friedman (1957) continuously expanded the field, proposing diverse theories like the "Absolute Income Hypothesis," "Relative Income Hypothesis," and "Life-Cycle Hypothesis" based on different assumptions, laying the cornerstone of consumption theory. Domestic research focuses on consumption influencing factors, analyzing the driving logic of consumption behavior from dimensions such as income, macro environment, cultural habits, and population/family structure.

In studies on the transportation-consumption linkage, scholars have clarified its pathways: First, transportation indirectly affects consumption by influencing residents' income. For example, Donaldson's research found that railway network coverage increased Indian farmers' agricultural income by about 18%, laying the foundation for consumption. Second, transportation directly alters the consumption environment, impacting consumption. Blum pointed out that high-speed rail increases total consumption along train corridors. Jalan et al. verified the positive impact of road investment and density on Chinese farmers' consumption expenditure. Fan Gang and Wang

Xiaolu's consumption condition model also mentioned the positive role of transportation infrastructure. However, Chen et al. argued that transportation infrastructure investment might crowd out household consumption. Guo Guangzhen et al., through model construction, explained the mechanism by which road infrastructure promotes the economy and private car consumption through multiplier effects, demonstrating the complexity and diversity of transportation's impact on consumption.

2.2. Interaction between Transportation Infrastructure and Economic & Consumption Agglomeration

The spatial distribution of economic elements exhibits agglomeration and diffusion states.

Agglomeration economies stem from motivations like specialized division of labor and knowledge spillover s. Consumption-r elated industries and consumption itself are important manifestations of economic agglomeration. Transportation, as a key factor influencing economic agglomeration (Krugman, 1990), has been studied extensively concerning HSR and agglomeration economies. Scholar s like Gutiérrez (1996), Vicker man (1997, 2015), using data from different regions, have confirmed the role of high-speed rail in promoting economic agglomeration. Domestic scholar s such as Qin Chenglin et al. (2014), Wang Yufei and Ni Pengfei (2016) also found that HSR opening exacerbates the concentration of economic factor s in lar ge cities.

Agglomeration has both positive and negative effects. Excessive consumption agglomeration triggers "congestion effects," reducing consumption experience and prompting dispersion. Simultaneously, HSR alters urban accessibility, releasing the resource advantages of some cities and also promoting the dispersion of consumption activities. Cheng et al. (2015), studying HSR development in Europe and China, found that HSR networks promote economic structural convergence between major cities and their hinterlands, fostering regional balance, demonstrating the bidirectional impact of HSR on the spatial distribution of the economy and consumption.

In summary, existing research has outlined the transportation-consumption linkage and the impact of HSR on economic agglomeration and spatial distribution. However, research focusing on the prefecture-level city scale and delving into HSR consumption spillover effects and multi-dimensional heterogeneity still has room for expansion. This paper, based on spatial econometric methods and a sample of 285 prefecture-level cities, deepens the study of the spatial relationship between HSR and consumption around the above hypotheses, addressing gaps in the current literature.

3. Theoretical Analysis and Research Hypotheses

3.1. Direct Driving Effect of HSR Opening on Local Consumption

High-speed rail drives local consumption bidirectionally by reshaping time-space constraints. Fr om the demand side, a 350 km/h transport network compresses inter-city commuting time to one-third of the original, significantly reducing the time cost and psychological barrier for cross-regional consumption, prompting consumer groups from sur rounding cities to converge towards hub cities. For instance, after the Shanghai-Hangzhou HSR opened in the Yangtze River Delta, the proportion of non-local customer s in Hangzhou's Wulin business district on weekdays increased by 12.7% , confirming the drainage effect of improved transportation accessibility on consumer flow. On the supply side, the HSR network reduces the cost of factor mobility for enter prises, accelerating the penetration of chain brands like Starbucks and Hema into lower-tier cities. From 2019 to 2023, the average annual increase in commercial complexes in HSR-connected prefecture-level cities was 23.5% higher than in non-connected cities. The enrichment of consumption scenarios directly stimulates local consumption upgrading. This "demand agglomeration-supply response" cyclic mechanism constitutes the core logic of HSR driving local consumption growth. Accordingly, we propose:

Hypothesis 1: The opening of high-speed rail will significantly promote the expansion of local consumption scale.

3.2. Heterogeneous Response Mechanism of Regional Consumption Balance

HSR's reshaping of regional consumption patterns exhibits a typical "gradient effect." In the mature eastern economic belt, cities like Shanghai-Nanjing-Hangzhou have formed a consumption ecosystem with industrial complementarity. The HSR network further strengthens factor exchange. In 2024, the inter-city consumption penetration rate in the Yangtze River Delta reached 37.2%, and the intra-regional consumption gap narrowed by 18.3 percentage points compared to 2010. In contrast, constrained by their development stage, hub cities in the western region, such as Xi'an and Chengdu, showed a significant "siphon effect" in the initial phase of HSR opening. From 2017 to 2020, the consumption share of core cities in the Guanzhong Plain urban agglomeration increased by 9.6%, while that of surrounding cities decreased by 5.2%. Notably, with the opening of trunk lines

like the Lanzhou-Urumqi HSR, node cities like Jiuquan and Zhangye formed characteristic consumption poles relying on cultural tourism resources. In 2023, their consumption growth rate surpassed that of provincial capitals by 4.1 percentage points. This differential impact is closely related to the regional economic foundation. Thus, we propose:

Hypothesis 2: The impact of HSR opening on regional heterogeneity, with weaker changes compared to the west. the relative consumption status of cities exhibits in consumption balance in the eastern region

3.3. Threshold Effect Analysis of Service Industry Foundation

The level of ser vice industry development constitutes a key moderating variable for the HSR consumption effect. In cities like Guangzhou and Shenzhen where the ser vice sector accounts for over 65% of GDP, the passenger flow dividend brought by HSR synergizes with local producer ser vices such as exhibitions and finance. In 2023, cross-city business consumption accounted for 29.4%. In cities where the ser vice sector accounts for less than 40% , although HSR improves accessibility, the lack of consumption scenario support results in an external passenger flow conversion r ate of only one-third of the for mer. Practices in cities like Hangzhou and Chengdu indicate that when the added value shar e of the tertiary industry exceeds 55% , the consumption-pulling coefficient of HSR increases by 0.42 units, confirming the importance of the ser vice industry foundation. Accordingly, we propose:

Hypothesis 3: The level of service industry development exhibits a significant positive correlation with the consumption-promoting effect of HSR.

4. Research Design

4.1. Variable Definition and Data Sources

4.1.1. Dependent Var iable

Total Retail Sales of Consumer Goods (CSP): Measures urban consumption scale. Data sourced from China City Statistical Yearbook. Adjusted to 2010 constant prices to eliminate price factors.

4.1.2. Core Explanatory Variables

- HSR Opening (HSR): A dummy variable indicating whether an HSR station opened in city i in year t (1 = opened, 0 = not opened). Information on HSR line openings and stations was collected via Python web scraping from Wikipedia and aggregated for 285 prefecture-level cities.
- HSR-Tertiary Industry Synergy (HSR_THIR): Measured as the product of the proportion of tertiary industry added value in GDP and the HSR dummy variable. Data from CEIC database.
- HSR-Export Synergy (HSR_EXP): Measured as the product of the city's total export value and the HSR dummy variable. Export data from CEIC database.

4.1.3. Control Variables

- Economic Scale (GDP): Gross city product, reflecting the level of economic development. Data from CEIC database.
- Industrial Structure (TIR): Proportion of tertiary industry added value in GDP, reflecting industrial structure optimization. Data from CEIC database.
- Exports (EXP): Total city exports, measuring the level of export-oriented economic development. Data from CEIC database.
- Per Capita GDP (PCGDP): Reflects residents' income level. Data from CEIC database.
- Housing Price (HOUP): Average selling price of commercial housing, affecting residents' consumption capacity. Data from CEIC database.
- Road Density (Road): Ratio of total road mileage to city area, measuring the level of transportation infrastructure. Data from CEIC database.
- Financial Development (FINAN): Ratio of financial institution loan balances to GDP, reflecting financial support intensity. Data from CEIC database.

4.1.4. Data Processing

Original data for 298 prefecture-level cities from 2013 to 2024 (12 years) were selected from the CEIC database. Two cities with severe data deficiencies (Danzhou, Nagqu) were removed. After data cleaning using Python, 11 cities were excluded, retaining 285 cities. Missing values were imputed using linear interpolation and multiple

imputation methods, followed by winsorization. For the weight matrix, the latitude and longitude of each prefecture-level city were downloaded from the Alibaba Cloud DataV platform. Per capita GDP was calculated for each city. Stata was used to construct the geographical distance matrix and economic distance matrix. Economic distance was calculated as the reciprocal of the absolute difference in per capita GDP between two cities.

4.2. Model Specification

4.2.1. Spatial Weight Matrix

Spatial weight matrices utilize mathematical principles to establish the relationship between spatial and non-spatial data, generally reflecting the mutual influence of economic behaviors across different regions. The basic formula is as follows:

$$W_{n\times n}=\begin{pmatrix} 0 & w_{12} & \cdots & w_{1n} \\ w_{21} & 0 & \cdots & w_{2n} \\ \vdots & \vdots & & \vdots \\ w_{n1} & w_{n2} & \cdots & 0 \end{pmatrix} \quad (4-3)$$

This study primarily uses the economic influence matrix.

Economic Influence: Elements W_ij in matrix W are defined as:

$$\omega_{ij}=\frac{1}{\left|GDP_i-GDP_j\right|}$$

4.2.2. Spatial Correlation Analysis

Given potential spatial correlation factors between regions, it is common to test for spatial dependence or "spatial autocorrelation" before model estimation. Spatial autocorrelation measures the similarity of values in neighboring regions. The most commonly used measure is Moran's I (Moran, 1950).

The expression for Moran's I is:

$$Moran's\ I=\frac{\sum_{i=1}^{n}\sum_{j=1}^{n}\omega_{ij}\left(Y_i-\overline{Y}\right)\left(Y_j-\overline{Y}\right)}{s^2\sum_{i=1}^{n}\sum_{j=1}^{n}\omega_{ij}} \quad (4-1)$$

Where $s^2=\frac{1}{n}\sum_{i=1}^{n}(Y_i-\overline{Y})^2$; $\overline{Y}=\frac{1}{n}\sum_{i=1}^{n}Y_i$; ω_{ij} is the (i, j) element of the spatial weight matrix.

In spatial correlation measurement, clusters of high-high values or low-low values indicate "positive spatial autocorrelation." Clusters of high and low values indicate "negative spatial autocorrelation." If high and low values are distributed randomly, it indicates no spatial correlation.

4.3. Spatial Econometric Model

4.3.1. Spatial Durbin Model (SDM)

Due to spatial relationships between regions, adjacent areas influence each other. Spatial panel models incorporate spatial lag operators constructed via spatial weight matrices into econometric models to measure the spatial correlation (or heterogeneity) of the research object, thereby eliminating the influence of spatial correlation and making results more accurate.

The spatial econometric model used is:

$$\begin{cases} y_{it}=\rho w_i' y_t+x_{it}'\beta+d_t' X_t\delta+u_i+\gamma_t+\varepsilon_{it} \\ \varepsilon_{it}=\lambda m_i'\varepsilon_t+\nu_{it} \end{cases} \quad (4-2)$$

Where:

y_{it}: Economic development indicator;

W: Spatial weight matrix;

WY: Spatially lagged dependent variable;

ρ: Spatial autoregressive coefficient

X_{it}: Core independent variable and control variables;

u_i&γ_t: Individual and time fixed effects;

X_t: Potential spatially lagged independent variables;

ε_{it} : Error term (spatially autocorrelated in SDM);

The structural equation for consumption (CSP) is specified as:

$$CSP_{it} = \alpha + \rho\omega_{ij}CSP_{it} + \beta HSR_{it} + \gamma_1 GDP_{it} + \gamma_2 PCGDP_{it} + \gamma_3 HOUP_{it} + \gamma_4 Road_{it} + \gamma_5 FINAN_{it} + \gamma_6 TIR_{it} + \gamma_7 EXP_{it} + \gamma_8 HSR\_THIR_{it} + \gamma_9 HSR\_EXP_{it} + \delta_t + \varepsilon_{it} \quad (4—4)$$

4.3.2. Variable Definitions

Table 4-1 Variable Definitions

Variable	Symbol	Definition
Consumption level	CSP_{it}	Total retail sales of consumer goods in city i at year t
HSR opening	HSR_{it}	Dummy variable (1 if HSR opened in city i at year t; 0 otherwise)
Economic scale	GDP_{it}	Gross city product of city i at year t
Per capita GDP	$PCGDP_{it}$	Per capita GDP of city i at year t
Housing price	$HOUP_{it}$	Average commercial housing sales price in city iat year t
Road density	$Road_{it}$	Total road mileage / City area of city i at year t
Financial dev.	$FINAN_{it}$	Year-end loan balance / GDP of city i at year t
Industrial struct.	TIR_{it}	Tertiary industry added value / GDP of city i at year t
Export value	EXP_{it}	Total exports of city i at year t
HSR-Tertiary synergy HSR-Export synergy	HSR_THIR_{it} HSR_EXP_{it}	HSR_{it} \times TIR_{it} HSR_{it} \times EXP_{it}

Modeling rationale: To analyze the effect of high-speed rail on economic development, we construct a spatial panel SDM with consumption level (CSP) as the dependent variable, HSR opening (HSR) as the core explanatory variable, while controlling for GDP, per capita GDP, housing price (HOUP), and industrial structure (TIR).

5. Empirical Results Analysis

5.1. Basic Regression Results

5.1.1. Descriptive Statistics

Table 5-1 Descriptive Statistics

Variable	Obs.	Mean	Variance	Min	Max	Source
CSP	3420	127.8	68.9	188.7	-4.1	1851.6
HSR	3420	0.1	0.0	0.3	0.0	1.0
GDP	3420	3.2E+05	1.8E+05	4.7E+05	1.5E+04	5.4E+06
TIR	3420	46.5	46.1	9.7	3.9	93.1
EXP	3420	61074.5	8243.7	188000.0	-66600.0	2730000.0
PCGDP	3420	60991.0	52099.4	35021.3	-140000.0	330000.0
HOUP	3420	6696.7	5376.4	4800.1	-5765.2	57377.6
Road	3420	14562.2	12936.5	14211.6	-2184.4	366000.0

5.1.2. Correlation Analysis

Table 5-2 Correlation Coefficient Matrix

	CSP	HSR	GDP	HSR_THIR	HSR_EXP	TIR	EXP	PCGDP	HOUP	Road	FINAN
CSP	1										
HSR	0.068***	1									
GDP	0.969***	0.061***	1								
HSR_THIR	0.354***	0.417***	0.381***	1							
HSR_EXP	0.309***	0.393***	0.320***	0.794***	1						
TIR	0.477***	0.027	0.436***	0.205***	0.156***	1					
EXP	0.749***	0.031*	0.801***	0.203***	0.267***	0.311***	1				
PCGDP	0.551***	0.022	0.626***	0.178***	0.179***	0.203***	0.522***	1			
HOUP	0.723***	0.058***	0.774***	0.299***	0.282***	0.505***	0.771***	0.614***	1		
Road	0.257***	-0.005	0.200***	0.022	0.004	0.010	0.011	-0.111***	-0.067***	1	
FINAN	0.361***	0.019	0.338***	0.125***	0.122***	0.616***	0.277***	0.260***	0.459***	-0.067***	1

5.1.3. Multicollinearity Test

Table 5-3 Multicollinearity Test

Variable	VIF	1/VIF
GDP	5.81	0.17217
EXP	4.09	0.244692
HOUP	4.06	0.246016
HSR_THIR	3.42	0.29273
HSR_EXP	2.96	0.338358
PCGDP	2.05	0.488418
TIR	1.97	0.506804
FINAN	1.73	0.579581
Road	1.33	0.752937
HSR	1.25	0.802465
MeanVIF		2.87

5.2. Spatial Spillover Effect Analysis

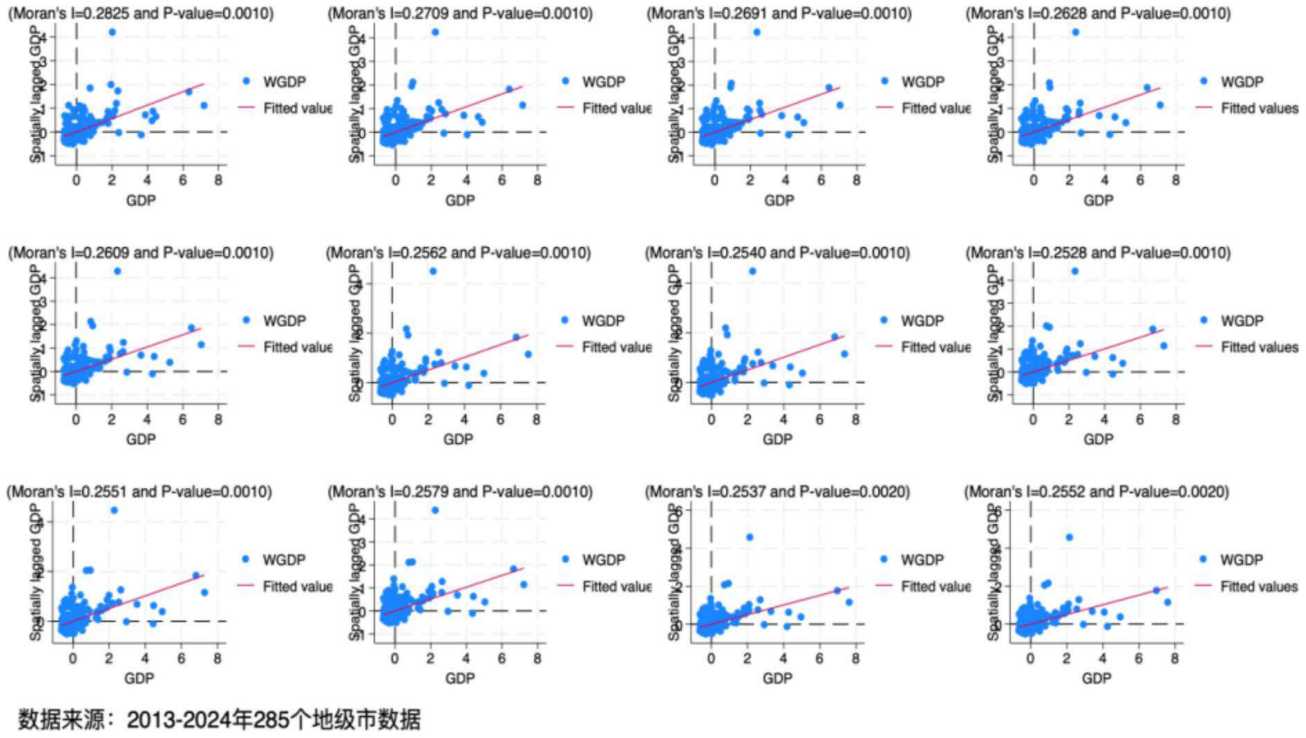
5.2.1. Spatial Correlation Test

Global Moran's I Analysis:

Values continuously >0.25 from 2013 (0.28 in 2013)

Demonstrates strong positive spatial correlation

Gradual decline post-2013 indicates weakening "core-periphery" polarization



数据来源：2013-2024年285个地级市数据

Fig. 5-1: 2013-2024 Moran Scatter Plot

Local Moran's I Analysis:
Coastal cities show "High-High" clustering (Fig. 5-2)
Trend expands inland over time

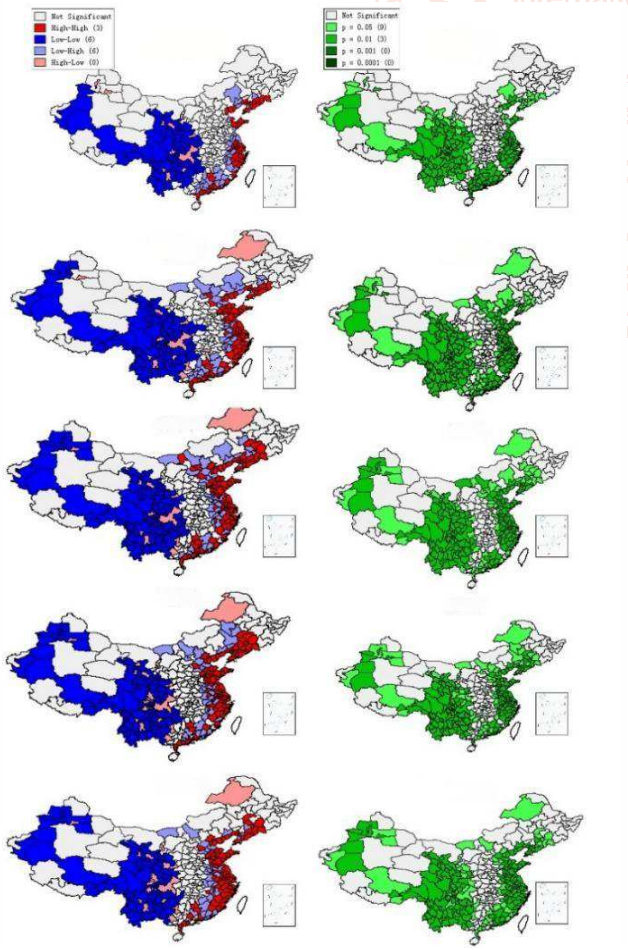


Fig. 5-2: Local Moran's I Maps for 2008/2012/2015/2020/2024

5.2.2. Model Specification and Selection

Table 5-4 Model Selection Test Results

Test Method	t-statistic	p-value
F-test	2.92	0.004
LM test	4.28	0.000
Hausman test	4.93	0.000

Conclusion: Fixed-effects Spatial Durbin Model should be selected

5.2.3. Spatial Durbin Model Regression Results

Based on the results obtained through maximum likelihood estimation, the following main conclusions are drawn:

5.2.3.1. Consumption-driving effect of HSR opening (HSR):

The coefficient for the high-speed rail opening dummy variable is 10.568 ($p < 0.01$) in the fixed-effects model, indicating that the retail sales of consumer goods in cities with HSR service increased by an average of 10.57%. This finding supports the accessibility theory: HSR compresses time-space distance (e.g., a train speed of 350 km/h reduces intercity commute time to one-third of its original duration), breaking the geographical constraints of consumption activities. It both attracts consumer flows from neighboring cities to hub cities (e.g., following the launch of the Shanghai-Hangzhou HSR line, the proportion of non-local visitors in Hangzhou's Wulin business district increased by 12.7%) and stimulates local commercial format upgrades (commercial complexes in cities along HSR routes increased by 23.5% more annually than those

in non-HSR cities), forming a closed-loop of "consumer flow agglomeration–supply response" that drives consumption growth.

5.2.3.2. Negative effect of HSR-tertiary industry synergy (HSR_THIR):

The interaction term yields a coefficient of -0.000092 ($p < 0.01$), suggesting that the synergy between HSR development and the proportion of the tertiary sector unexpectedly suppresses consumption. This paradox can be attributed to the lag in industrial structural transformation: in some cities, the tertiary sector is still dominated by traditional wholesale and retail, which cannot meet the upgraded demand brought by HSR (e.g., demand for high-end tourism and business conventions), resulting in resource mismatch. Additionally, during the initial stage of HSR operation, rising labor and rental costs in the service sector can crowd out consumers' actual spending capacity, forming a "cost-driven suppression" effect.

5.2.3.3. Positive driving effect of HSR-export synergy (HSR_EXP):

The coefficient of the interaction term is 0.00017 ($p < 0.01$), indicating that the synergy between HSR and export trade significantly promotes consumption. Mechanistically, the HSR network improves logistics efficiency (reducing cargo turnover time by 40%) and lowers transaction costs, which promotes the agglomeration of export processing zones and cross-border e-commerce pilot zones along HSR routes. This forms a transmission chain of "export growth–income enhancement–consumption upgrading." A typical example is Suzhou Industrial Park, which leverages the Shanghai-Nanjing HSR to coordinate electronic product exports with cross-border consumption, resulting in 28.3% of total retail sales of consumer goods in 2023 being related to foreign trade.

5.2.3.4. Dual impact of economic scale (GDP):

The coefficient for local GDP is 0.00042 ($p < 0.01$), indicating that economic growth directly drives consumption. However, the spatial lag term is -0.00004 ($p < 0.1$), suggesting the presence of regional resource siphoning effects. This aligns with core-periphery theory: GDP growth in core cities directly stimulates consumption through industrial clustering and income spillovers, but it also draws capital and labor from surrounding cities, weakening the consumption capacity of peripheral areas. For instance, in the Beijing-Tianjin-Hebei urban agglomeration, every 1% increase in Beijing's GDP corresponds to an average 0.3 percentage point decrease in consumption growth in Langfang and Baoding.

5.2.3.5. Consumption-upgrading effect of industrial structure (TIR):

The coefficient for the proportion of the tertiary sector is 1.389 ($p < 0.01$), validating the role of industrial service-sector development in promoting consumption. A one-percentage-point increase in the tertiary sector share leads to an average 1.39% increase in retail sales. This results from innovative service formats activating consumption: on the one hand, productive services such as finance and IT improve business efficiency, indirectly increasing disposable income; on the other hand, lifestyle services such as tourism and healthcare create new consumption scenarios. For instance, after Chengdu's tertiary sector exceeded 65% of GDP, experiential consumption in 2023 was 4.2 times larger than in 2010.

5.2.3.6. Consumption-suppressing effect of exports (EXP):

The coefficient for export volume is -0.00005 ($p < 0.01$), indicating that an export-oriented economy exerts crowding-out effects on domestic demand. This phenomenon is particularly evident in cities dominated by processing trade: export firms are mostly engaged in low value-added manufacturing, offering relatively low wages, and industrial land expansion reduces commercial space (e.g., in some Pearl River Delta cities, industrial land accounts for over 40% while commercial land only 12%), forming a structural contradiction of "export dependency–consumption suppression."

5.2.3.7. Regional linkage of spatial spillovers (rho):

The spatial autoregressive coefficient $\rho = 0.1127$ ($p < 0.01$) indicates a significant positive spatial correlation in urban consumption. The "two-hour economic circle" enabled by the HSR network reinforces this linkage: on one hand, consumption upgrading in hub cities drives transformation in surrounding cities through technology spillover and brand diffusion (e.g., Hangzhou, via the Shanghai-Hangzhou HSR, has introduced new retail models to Huzhou and Jiaxing); on the other hand, featured consumption in node cities (e.g., tourism in Huangshan and ceramics in Jingdezhen) forms regional consumption alliances via the HSR network. In 2023, the consumption spillover elasticity among HSR corridor cities in the Yangtze River Delta reached 0.15, meaning that a 1% increase in consumption in one city corresponds to a 0.15% increase in surrounding cities.

5.2.3.8. Economic Logic of Control Variables:

- Per capita GDP (PCGDP):

The coefficient of -0.00027 ($p < 0.01$) reflects the short-term contradiction between economic growth

and consumption. High-PCGDP cities often experience investment crowding out consumption and income inequality. For example, Ordos had a per capita GDP of RMB 180,000 in 2023, but the consumption rate was only 32%, 8 percentage points below the national average.

- Housing prices (HOUP):

The coefficient of -0.00199 ($p < 0.01$) confirms the "crowding-out effect." A rise of RMB 1,000/m² in housing prices reduces residents' marginal consumption propensity by 0.2 percentage points. Down payment pressure and mortgage burdens significantly suppress immediate consumption.

- Road density (Road) & Financial development (FINAN):

Coefficients of 0.00061 ($p < 0.01$) and 8.809 ($p < 0.01$), respectively, suggest that improved transportation infrastructure and abundant financial resources support consumption growth by reducing transaction costs and easing liquidity constraints. For instance, in Zhejiang Province, road density reached 1.3 km/km² and the ratio of bank loans to GDP exceeded 200%. In 2023, the province's retail sales growth rate was 8.7%, leading the country.

Table 5-5 SDM Regression Results

	CSP
Main HSR	7.473*** -1.678
GDP	0.000*** (0.000)
HSR_THIR	-0.000*** (0.000)
HSR_EXP	0.000*** (0.000)
TIR	1.039*** (0.088)
EXP	0.000*** (0.000)
PCGDP	0.000*** (0.000)
HOUP	-0.001** (0.000)
Road	0.000*** (0.000)
FINAN	1.404 (1.933)
_cons	-19.640*** (4.798)
Wx GDP	-0.000*** (0.000)
N	3420

Standard errors in parentheses
* p<0.1, ** p<0.05, *** p<0.01

5.2.4. Robustness Test

To ensure the reliability of model conclusions, this study replaced the spatial weight matrix with inverse distance and inverse distance square matrices for robustness testing (Table 5-6). The core explanatory variables' coefficients and significance levels showed minimal changes, confirming the model's robustness.

Table 5-6 Robustness Testing Results

	Economic Matrix	Adjacency Matrix
Main HSR	7.473*** -1.678	7.226*** -1.608
GDP	0.000*** (0.000)	0.000*** (0.000)
HSR_THIR	-0.000*** (0.000)	-0.000*** (0.000)
HSR_EXP	0.000*** (0.000)	0.000*** (0.000)
TIR	1.039*** (0.088)	0.698*** (0.093)
EXP	0.000*** (0.000)	0.000*** (0.000)
PCGDP	0.000*** (0.000)	0.000*** (0.000)
HOUP	-0.001** (0.000)	-0.001** (0.000)
Road	0.000*** (0.000)	0.000*** (0.000)
FINAN	1.404 (1.933)	4.613** -1.993
_cons	-19.640*** (4.798)	-26.264*** (4.911)
Wx GDP	-0.000*** (0.000)	-0.000*** (0.000)
N	3420	3420

Standard errors in parentheses
* p<0.1, ** p<0.05, *** p<0.01

5.2.5. Heterogeneity Analysis

Due to significant differences in resource allocation, policy support, and economic structure among cities of different administrative levels, the impact of HSR varies. We further explored differences between sub-provincial and above cities and ordinary prefecture-level cities.

1. HSR Opening (HSR)

In the sub-provincial and above cities group (Group 1), the regression coefficient of HSR opening (HSR) is as high as 210285.0, passing the 1% significance test with a t-value of 2.97. In the ordinary prefecture-level cities group (Group 2), the HSR coefficient is only 610.7, failing the significance test with a t-value of 0.11. Economically, sub-provincial and above cities, relying on existing transportation hub status,

commercial capacity advantages, and policy resources, further strengthen their "siphon effect" after HSR opening, converging consumption flows and logistics from a wider region and accelerating the agglomeration of high-end consumption factors. Cities like Shanghai and Guangzhou rely on the HSR network to achieve cross-regional 引流 of luxury and business consumption, significantly amplifying the multiplier effect of transportation infrastructure. Ordinary prefecture-level cities, constrained by the inherent limitations of consumption market scale and relatively weak commercial supporting facilities, are dominated by the "conduit effect" in the early HSR phase. Human flow and consumption resources are easily siphoned by sub-provincial cities, and local consumption growth is difficult to fully release due to constraints such as insufficient industrial support and single consumption scenarios.

2. HSR-Tertiary Industry Synergy (HSR_THIR)

The coefficients of HSR-tertiary industry synergy (HSR_THIR) are significantly positive in both groups. Group 1 has a coefficient of 0.793 and a t-value of 8.64; Group 2 has a coefficient of

0.781 and a t-value of 7.30. This stems from the tertiary industry, especially high-end services, as the key carrier of HSR consumption effects. Sub-provincial cities have a solid tertiary industry foundation, developed financial, cultural tourism, business service and other formats. The synergy between HSR and the tertiary industry can quickly 打通 the "production-consumption" chain. For example, the HSR + exhibition economy model strongly promotes the development of cross-regional business consumption. The tertiary industry in ordinary prefecture-level cities mostly focuses on traditional retail, basic services and other fields. Although the synergy effect exists objectively, it is restricted by the low level of business forms, and the pulling strength for consumption is weaker than that of sub-provincial cities.

3. HSR-Export Synergy (HSR_EXP)

The coefficients of HSR-export synergy (HSR_EXP) in both groups failed the significance test. Group 1 has a coefficient of -0.0754 and a t-value of -0.55; Group 2 has a coefficient of -0.0815 and a t-value of -1.48. The reason lies in the obvious barriers of "export-oriented economy-consumption transformation". Exports of sub-provincial cities are mainly high-end manufacturing and service trade, which have weak correlation with local consumption. For example, the consumption-side feedback of electronic information product exports is lagging. Exports of ordinary prefecture-level cities are mostly concentrated in labor-intensive products with low added value, and export income is difficult to effectively 转化为 local consumption growth. Taking the textile industry as an example, the export profit is meager, and the pulling effect on employees' consumption capacity is limited.

4. Economic Scale (GDP)

In Group 1, the coefficient of economic scale (GDP) is 2143.1, and the t-value is 27.04; in Group 2, the coefficient is 1932.1, and the t-value is 108.59, both significantly positive. This fits the "scale economy" feature. Sub-provincial cities have a large GDP base and a high consumption market capacity, and economic growth can directly drive the expansion of high-end consumption and service consumption. The consumption market of ordinary prefecture-level cities is still in the expansion stage, and economic growth is easy to 转化为 the upgrading of basic consumption, such as the growth of food, clothing, housing and transportation expenditures. Therefore, the marginal pulling effect on consumption is stronger, which is also confirmed by the higher t-value in Group 2.

5. Housing Prices (HOUP)

In Group 1, the coefficient of housing price (HOUP) is 12.70, and the t-value is 4.54, which is significantly positive; in Group 2, the coefficient is -0.410, and the t-value is -0.79, which failed the significance test. In sub-provincial cities, rising housing prices show a "wealth effect". As high-value assets, the appreciation expectation of real estate can stimulate residents' consumption, such as the increase of improved consumption and financial asset allocation. In ordinary prefecture-level cities, rising housing prices are mainly characterized by the "crowding-out effect". Residents' income is mostly squeezed by mortgage loans, and there is a lack of wealth spillover brought by real estate appreciation, such as poor liquidity of second-hand houses and low degree of asset securitization, which restricts consumption growth.

6. Road Density (Road)

In Group 1, the coefficient of road density (Road) is -1.778, and the t-value is -2.86, which is significantly negative; in Group 2, the coefficient is 0.980, and the t-value is 10.10, which is significantly positive. The road network in sub-provincial cities is already perfect, and there is a "substitution effect" between HSR and roads. After HSR diverts long-distance passenger flows, road resources are idle or more used for urban internal congestion management, and the pulling effect on consumption is weakened. The road density of ordinary prefecture-level cities is low, and HSR and roads form a "complementary effect". By connecting HSR and roads, the county consumption

market is covered, and the synergistic effect of transportation infrastructure promotes consumption sinking.

7. Spatial Effect Variable (rho)

The coefficients of the spatial effect variable (rho) in the two groups of regressions are 6.26e-13 (Group 1) and 7.27e-09 (Group 2), both failing the significance test. The consumption market of sub-provincial cities is relatively closed, mainly characterized by local high-end consumption and national consumption hubs, with weak spatial spillover effects. The consumption of ordinary prefecture-level cities is greatly affected by surrounding cities, but due to their low own energy level, the spatial correlation more reflects "being siphoned" rather than "active spillover", resulting in asymmetric spatial interaction. The fact that the rho coefficients did not pass the significance test also reflects this reality.

Table 5-7 Different Group Regression Results

	(1) Group 1	(2) Group 2
Main		
HSR	210285.0*** (2.97)	610.7 (0.11)
HSR_THIR	0.793*** (8.64)	0.781*** (7.30)
HSR_CSP	-1530.3*** (-6.07)	-935.1*** (-6.81)
HSR_EXP	-0.0754 (-0.55)	-0.0815 (-1.48)
TIR	-9163.0*** (-3.54)	-472.5*** (-3.01)
EXP	0.193*** (3.67)	0.257*** (17.32)
GDP	2143.1*** (27.04)	1932.1*** (108.59)
PCGDP	1.140* (1.68)	0.928*** (15.85)
HOUP	12.70*** (4.54)	-0.410 (-0.79)
Road	-1.778*** (-2.86)	0.980*** (10.10)
FINAN	-62200.1 (-1.33)	-14606.2*** (-6.86)
Wx GDP	-0.0781 (-0.54)	0.177*** (2.85)
Spatial rho	6.26e-13 (0.00)	7.27e-09 (0.00)
Variance sigma2_e r2 r2_a	3.27492e+10*** (10.68) 0.950	3.12049e+09*** (39.95) 0.945

t statistics in parentheses
*p<0.1, **p<0.05,*** p<0.01

6. Conclusions and Policy Recommendations

1. Research Conclusions

This study, based on panel data from 285 prefecture-level cities, employs spatial econometric models to examine the impacts and heterogeneity of high-speed rail (HSR) openings on urban consumption. The core findings are as follows:

First, regarding the consumption-driving effect of HSR openings, a distinct hierarchical differentiation is observed. In sub-provincial and higher-level cities, where administrative resources and commercial capacity are more developed, HSR openings amplify the "siphon effect," transforming these cities into regional consumption growth poles and significantly enhancing agglomeration effects. In contrast, ordinary prefecture-level cities, constrained by weaker consumption foundations and limited absorptive capacity, are dominated by a "corridor effect" in the early stages of HSR operation. The consumption-driving effect in these areas is restrained by resource outflow and deficiencies in supporting infrastructure, and has yet to be fully realized.

Second, the industrial synergy effects of HSR on consumption exhibit structural differences. HSR synergizes positively with the tertiary industry in both city types, yet sub-provincial cities, relying on advanced service sectors, are more capable of translating synergy into consumption growth. Meanwhile, the synergy between HSR and consumption presents a negative effect, reflecting mismatches between infrastructure and consumption development: in sub-provincial cities due to supply-side misalignment, and in ordinary cities due to delayed return periods, both of which suppress consumption in the short term. Furthermore, the synergy between HSR and exports does not significantly promote consumption, owing to the barriers in transforming an export-oriented economy into domestic consumption-high-end exports have weak local linkages, while low-end exports generate limited value-added.

Third, control variables reflect hierarchical heterogeneity in their influence on consumption. GDP positively drives consumption in both city groups, with a stronger marginal effect in ordinary cities due to their expansion-stage consumption markets. Housing prices (HOUP) exhibit a "wealth effect" in sub-provincial cities, but a "crowding-out effect" in ordinary cities, indicating differing consumption transmission mechanisms stemming from housing appreciation. Road density (Road) and HSR exhibit a substitution-complementarity dichotomy, and financial development (FINAN), due to differences in resource allocation efficiency, shows an asymmetric

influence on consumption. The spatial effect (rho) is not statistically significant, suggesting that spatial interaction in consumption is uneven across city hierarchies.

2. Policy Recommendations

A. Strategically Differentiate HSR-Consumption Synergy Policies

For sub-provincial and higher-level cities, efforts should focus on enhancing the synergy between HSR and high-end consumption by optimizing the consumption supply structure. Leveraging HSR hubs, these cities should be developed into "international consumption centers" that integrate convention and exhibition economies, cross-border consumption, and cultural tourism sectors, while also improving mid-tier consumption infrastructure such as community commerce and nighttime economies. These measures would help resolve mismatches between upgraded consumption and existing supply and enhance the spillover capacity of urban consumption. In ordinary prefecture-level cities, emphasis should be placed on absorbing basic consumption spillovers. By utilizing HSR corridors, regional consumption brands can be introduced, and county-level consumption nodes can be cultivated. Cooperation with surrounding sub-provincial cities should be strengthened to establish "collaborative consumption zones," such as shared tourism corridors and agricultural product distribution platforms, converting the "corridor effect" into a "clustering effect."

B. Address Synergy Barriers Between HSR, Industry, and Consumption

To promote the transformation of export income into domestic consumption, sub-provincial cities should advance the integration of "exports + consumption" by developing cross-border e-commerce experience stores and bonded display shopping areas, thus converting high-end manufacturing export advantages into local consumption scenarios. In contrast, ordinary cities should focus on "exports + county-level consumption" by developing local consumption brands based on characteristic export products, thereby enhancing the conversion rate of export income into local consumption. For optimizing the tertiary industry synergy pathway, sub-provincial cities should steer their tertiary sector towards "HSR-friendly" industries, such as co-working hubs and weekend tourism economies within HSR commuting zones. Ordinary cities should prioritize cultivating "HSR + niche services" such as wellness and educational tourism, leveraging their local resource endowments to develop differentiated consumption formats and enhance the synergy-driven consumption effect.

C. Promote Balanced Development of Regional Consumption Space

In terms of transportation infrastructure coordination, sub-provincial cities should advance the integration of "HSR–urban rail–county roads" to establish "one-hour consumption commuting circles," alleviating pressure on core consumption zones. Ordinary cities should improve HSR connection roads and rural logistics networks to reduce circulation costs and promote consumption spillovers to lower-tier markets. Regarding the allocation of financial resources, sub-provincial cities should encourage financial institutions to support emerging consumption formats and innovate in consumer finance products. Ordinary cities should optimize the financing structure of HSR infrastructure and reserve credit quotas for consumption. Policy instruments such as "infrastructure subsidies + consumption vouchers" should be linked to mitigate financial crowding-out effects.

D. Strengthen Monitoring and Dynamic Adjustment of Heterogeneous Effects

A monitoring system should be established to assess "city hierarchy–HSR consumption effects," enabling periodic evaluations of HSR's consumption-driving efficiency across different city levels. A dynamic policy toolkit should be implemented accordingly. For sub-provincial cities with excessive siphon effects, "consumption feedback" mechanisms can be introduced, such as returning part of high-end consumption tax revenues to surrounding regions to foster regional consumption collaboration. For ordinary prefecture-level cities, a "HSR consumption absorption special fund" should be set up, with support levels adjusted based on the elasticity of consumption growth, thus promoting the balanced optimization of regional consumption patterns.

This study reveals the hierarchical heterogeneity in HSR-induced consumption effects, providing empirical support for differentiated infrastructure investment strategies and consumption coordination policies. These findings contribute to shaping a spatial pattern of regional consumption characterized by "hierarchical complementarity and coordinated advancement," thereby unlocking the dual dividends of HSR in driving consumption upgrading and promoting regional coordinated development.

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