中国科学院大学
University of Chinese Academy of Sciences

Paving the Way

Investigating the Impact of High-Speed Rail Connectivity and Information Connectivity on Industrial Transfer Between Cities from A Perspective of Multiple Factor Flows

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CONTENTS

Research Background: The Evolution of Industrial Transfer in China

1949

1949-1978
Stage1: industrial layout under the planned economy

Key points: The state leads the industrial layout through the planned economy, with heavy industry and defense industry as the core, and promotes the transfer of industries to the northeast and central and western regions.
Symbol: "Three-line" construction: for war preparation, the state transferred part of the industries in the coastal and northeast regions to the central and western regions, forming new industrial such as Panzhihua and Liupanshui.

1978

1978-2000
Stage2: Priority development of the coastal areas in the early stage of reform and opening up

Key points: Strategy of giving priority to coastal development, and promotes the agglomeration of industries in eastern coastal areas through policies such as setting up special economic zones and opening up coastal cities.
Symbol: *"Decision on Economic Restructuring"* (1984) : proposed to accelerate the opening up of coastal areas to the outside world, promote the development of light industry and labor-intensive industries; *Decision on Several Issues Concerning the Establishment of a Socialist Market Economy System* (1993) : Further clarifying the role of the market in resource allocation and promoting the eastern coastal areas to become a global manufacturing base.

2000

2000-2020
Stage3: regional coordinated development and industrial gradient transfer

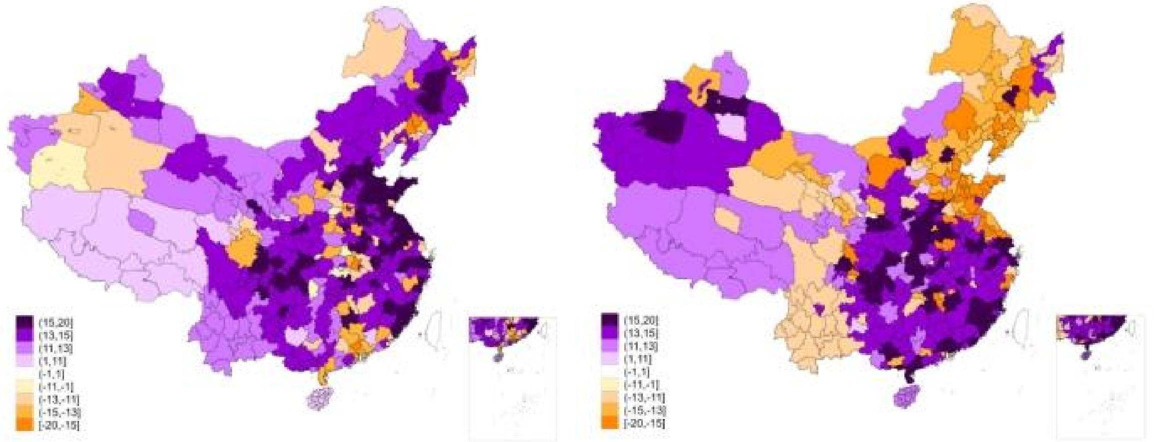
Key points: Coordinated regional development strategy was proposed to promote the transfer of industries from the eastern coastal areas to the central, western and northeast China, promoting the gradient development of industries.
Symbol: N*otice on the Implementation of Policies and Measures for the Development of the Western Region* (2000) : It proposes to attract the transfer of industries from the eastern region to the western region through preferential tax policies and financial transfer payments; *The Guiding Opinions on Undertaking Industrial Transfer in Central and Western Regions* (2010) promotes industrial transfer at the national level.

2020

2020 to the present
Stage4: High-quality development and the new development pattern

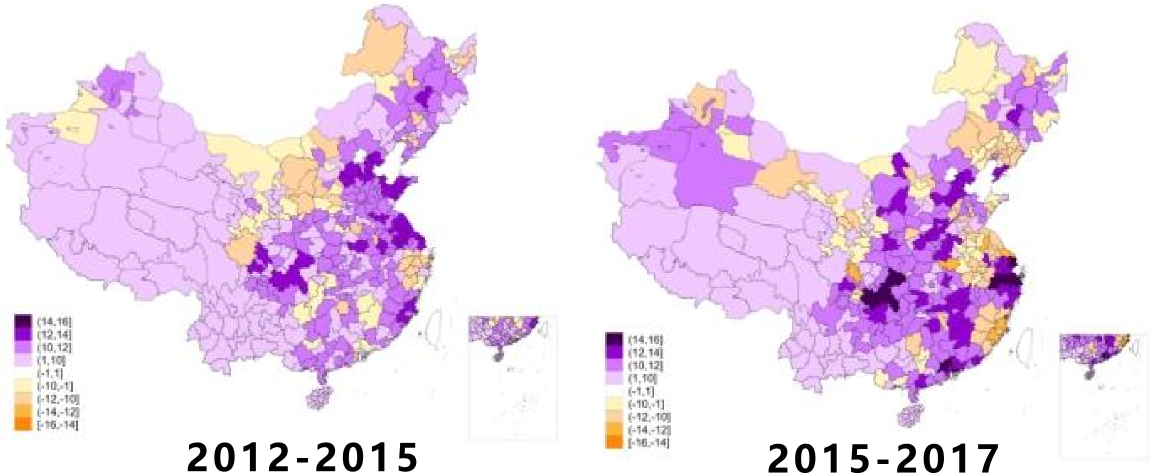
Key points: The state proposes high-quality development and a new development pattern to promote the transfer of industries to the central and western regions and northeast China, while strengthening the security of industrial chains and supply chains to promote the development of high-end, intelligent and green industries.
Symbol: *Domestic and international double circulation* (2020), accelerating the construction of a new development pattern; *Opinions on Accelerating the Construction of a Unified National Large Market* (2022) : Emphasizing on breaking local protection and market segmentation, and promoting the optimal layout of industries across the country. *The Third Plenary Session of the 20th Central Committee of the Communist Party of China* (2024) : the strategic deployment of "improving the cooperation mechanism of orderly gradient transfer of industries in China"

Research background: The spatio-temporal evolution of industrial transfer between cities



2012-2015 2015-2017

Spatial Distribution of Industrial Transfer Scales Received by Cities



2012-2015 2015-2017

Spatial Distribution of Industrial Transfer Scales Received from Beijing

- **From 2012 to 2015**, industrial transfer in China was mainly concentrated in the eastern coastal areas, with the Chengdu-Chongqing urban agglomeration in the west and the Harbin-Changchun urban agglomeration in the northeast serving as secondary recipients. Most of the central regions were mainly exporters of industries, presenting a distinct phenomenon of **"central collapse"**.
- **From 2015 to 2017**, industries mainly gathered in the southeast, with the northeast and north China regions becoming the main exporters of industries. The "central collapse" phenomenon almost vanished, and Xinjiang and other places became new recipients of industries.
- Transformation **from "central collapse and coastal concentration" to accelerated transfer to the central and western regions.**

- **From 2012 to 2015**, the industries of Beijing mainly transferred to neighboring regions, with the Beijing-Tianjin-Hebei urban agglomeration, the Bohai Rim Economic Zone, Jiangsu Province and the Chengdu-Chongqing urban agglomeration being the main recipients.
- **From 2015 to 2017**, although the Beijing-Tianjin-Hebei urban agglomeration remained one of the main recipients of Beijing's industrial transfer, the transfer was no longer confined to neighboring areas. Instead, it presented a new feature of **diversified transfer directions**: the scope of industrial transfer to the west and south was extended. At the same time, the recipients of industrial transfer showed **a new feature of clustering** (such as the Beijing-Tianjin-Hebei, Guanzhong Plain, Chengdu-Chongqing, Yangtze River Delta, Pearl River Delta and so on).

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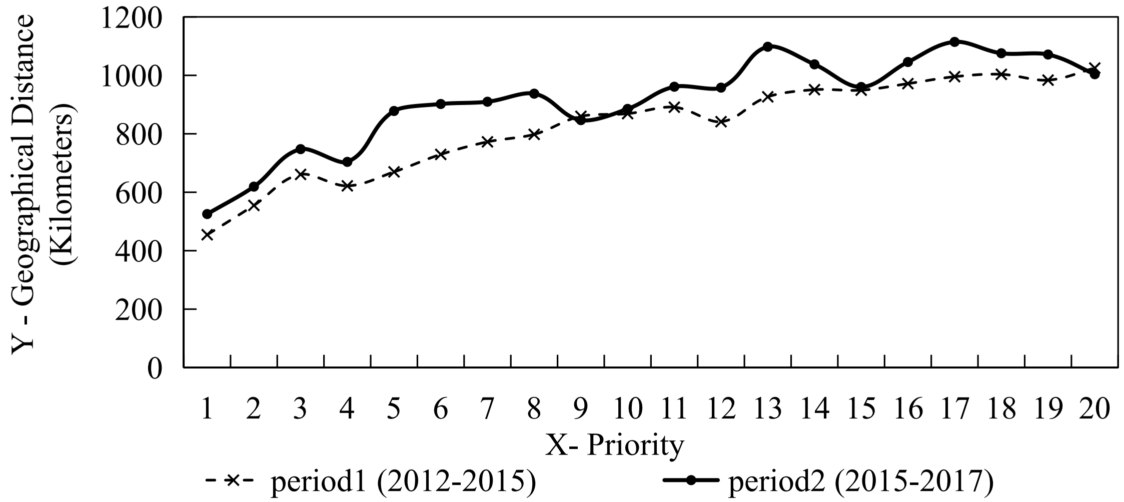
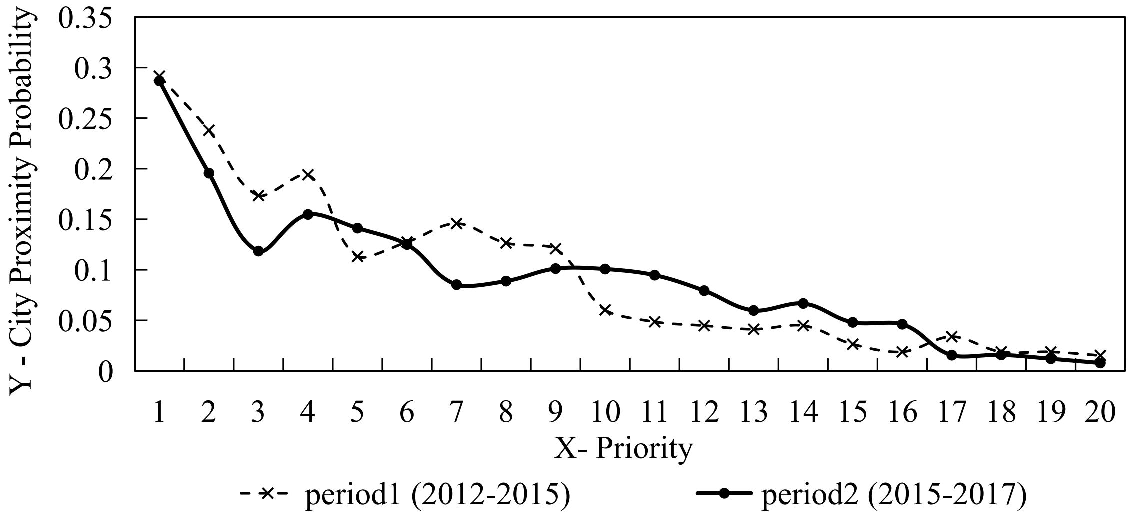


Geographical Distance Distribution of Industrial Priority Transfer Targets (Top 20)



Probability Distribution of Choosing Neighboring Cities as Industrial Priority Transfer Targets (Top 20)

- Geographical distance is basically positively correlated with priority. Generally, when urban industries transfer, cities with closer geographical distances are preferred. **Geographical distance is an important consideration factor.**
- The geographical distance in period 2 is overall greater than that in period 1. Therefore, over time, the industrial transfer shows an overall trend of **outward diffusion geographically**.
- Further comparing the volatility of the two curves, the curve of the old period is generally in a straight upward trend, while the curve of the new period has stronger volatility. This indicates that over time, **the factors influencing industrial transfer between cities have gradually diversified**, and geographical distance is no longer the sole constraint.

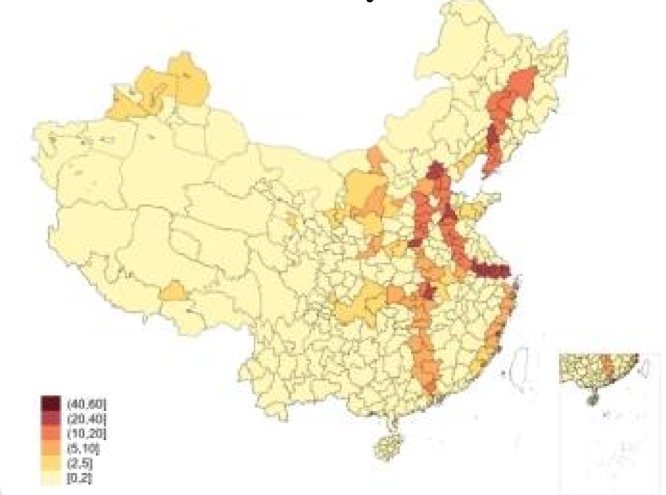
- Whether in period 1 or period 2, the probability of choosing nearby cities as the primary target for industrial transfer remained almost unchanged (0.3), indicating that nearby cities have always been the preferred choice for industrial transfer.
- In comparison, in the old period, the probability density of nearby cities being the preferred destination for industrial transfer was concentrated in the top 10, while in the new period, the probability distribution became relatively more uniform.
- Over time, **although the preferred position of nearby cities is difficult to be challenged, non-adjacent cities have gained more opportunities to undertake industrial transfer.**

Research background: Spatial-Temporal Evolution of Inter-City Connectivity

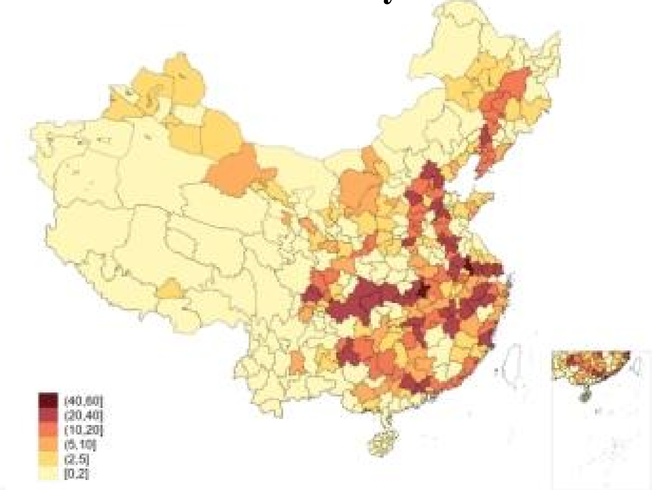
Currently, the inter-city connectivity mainly takes **two forms**:

- **The traditional physical connection represented by high-speed railways**, which relies on large-scale infrastructure construction and uses physical transportation routes to shorten the time and space distance between cities, featuring large transportation volume and strong stability. This article measures the level of high-speed rail connectivity (traditional connection) between cities based on the number of high-speed railway lines opened between cities.
- The new connection in the era of informatization and digitalization, leveraging technologies such as the Internet and big data, breaks down information barriers and realizes the sharing and collaboration of data and resources between cities, featuring immediacy and virtuality. This article measures the level of information connectivity (new connection) between cities based on the logarithm of Baidu search index between cities.

2012 Spatial Distribution of HSR Connectivity Network Centrality for Cities



2015 Spatial Distribution of HSR Connectivity Network Centrality for Cities



2024 Edition Map of China's High-Speed Railway Network

In 2012, the Beijing-Guangzhou HSR was fully completed, marking the **initial formation of the "Four Vertical & Four Horizontal"** main framework. The **cities along the "Four Vertical"** routes demonstrated a significant advantage in concentrated HSR connectivity within the network, linking core urban clusters such as the Beijing-Tianjin-Hebei region, the Yangtze River Delta. Cities like Shenyang, Beijing, Jinan, Zhengzhou, Wuhan, Nanjing, and Shanghai became **the first batch of high-speed railway hub cities.**

In 2017, the "four longitudinal and four lateral" railway network was basically completed. On this basis, it further developed into the **"Eight Vertical & Eight Horizontal" high-speed railway network**. The coverage and connectivity of high-speed rail significantly improved, **the horizontal connections of high-speed rail lines were enhanced, the high-speed railway network extended westward**, and the Chengdu-Chongqing urban agglomeration and the Qianzhong urban agglomeration became new hubs.

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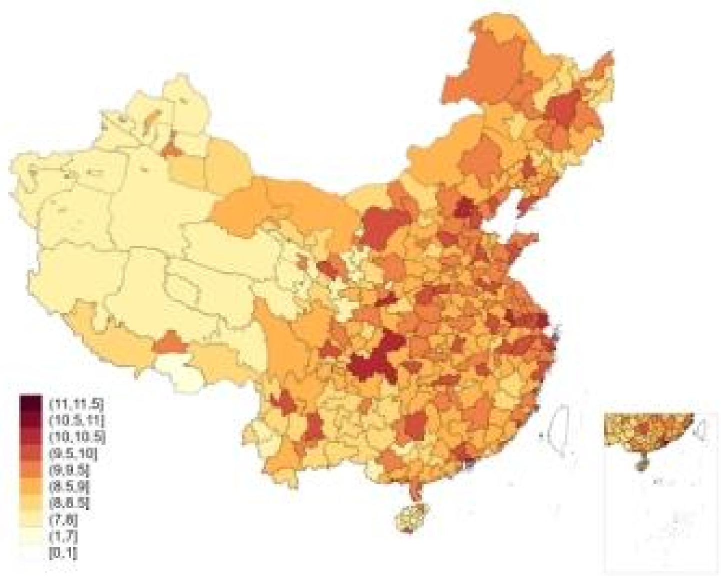
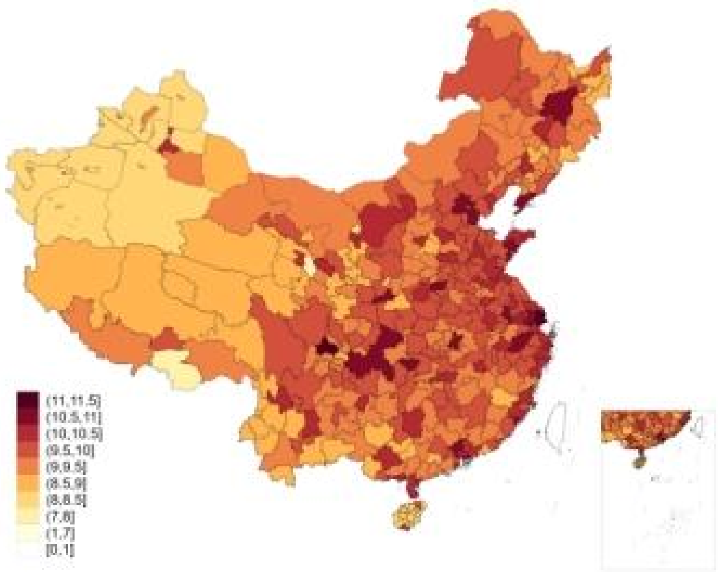
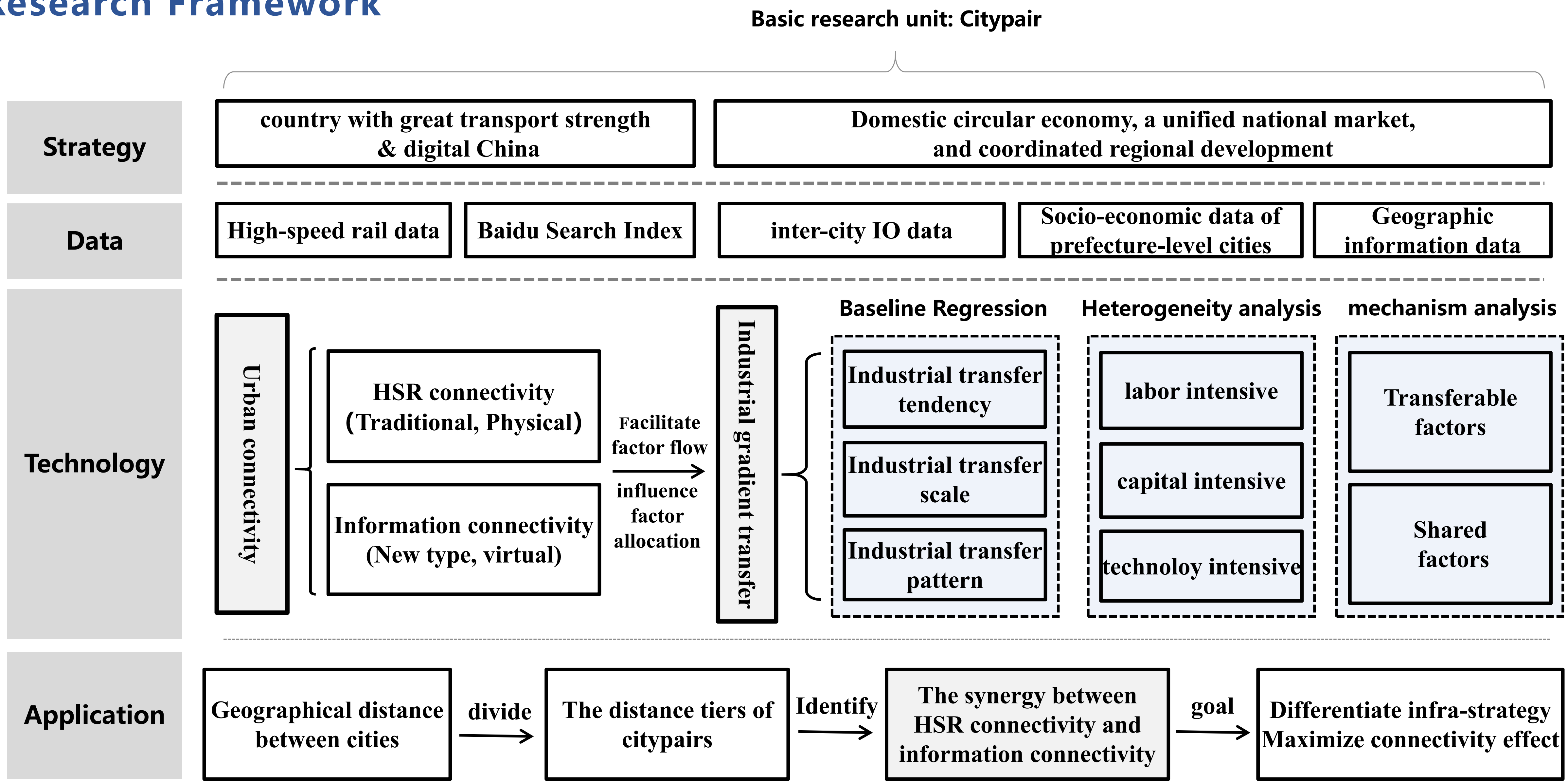


2017 Spatial Distribution of Information Connectivity Network Centrality for Cities



- With the acceleration of China's informatization construction, the penetration rate of the Internet has significantly increased, and **the information connections among cities have gradually strengthened.**
- In China's information network in 2012, the information connectivity level showed an overall feature of being higher in the east than in the west, and higher in the coastal areas than in the inland areas.
- In 2017, **information connections extended westward and inlandward.** Among them, the Beijing-Tianjin-Hebei region, the Yangtze River Delta, the Pearl River Delta and the Chengdu-Chongqing urban agglomeration remained as the hubs of information connections.

Research Framework



Measurement of Industrial Transfer

- This paper refers to the research published by Liu Hongguang et al. (2011) in "China Industrial Economy", and adopts the method based on the input-output model to measure industrial transfer between cities. It can quantify the scale of **two-way industrial transfer** between regions.
- Different from the regional industrial transfer of Liu Hongguang et al. (2011), this study measures **industrial transfer between prefecture-level cities** based on the multi-regional input-output table data of 309 prefecture-level cities in China released by the CEADs team in **2012, 2015 and 2017**.

According to the Leontief input-output model theory, the total output of a city is X, the final demand is Y, and the direct consumption coefficient matrix is A. Then it satisfies the following relationship:

$$X = (I - A)^{-1} Y$$

For n cities, the calculation of the total output matrix is as follows. Here, Xij represents the total output of city i caused by the final demand of city j.

$$\begin{pmatrix} X_{11} & \cdots & X_{1n} \\ \vdots & \ddots & \vdots \\ X_{n1} & \cdots & X_{nn} \end{pmatrix} = \begin{pmatrix} I - A_{11} & \cdots & -A_{1n} \\ \vdots & \ddots & \vdots \\ -A_{n1} & \cdots & I - A_{nn} \end{pmatrix}^{-1} \begin{pmatrix} Y_{11} & \cdots & Y_{1n} \\ \vdots & \ddots & \vdots \\ Y_{n1} & \cdots & Y_{nn} \end{pmatrix}$$

Suppose there are two time points, t and t + 1. Then the total output change ΔX of these n cities is:

$$\begin{pmatrix} \Delta X_{11} & \cdots & \Delta X_{1n} \\ \vdots & \ddots & \vdots \\ \Delta X_{n1} & \cdots & \Delta X_{nn} \end{pmatrix} = \begin{pmatrix} X_{11}^{t+1} - X_{11}^{t} & \cdots & X_{1n}^{t+1} - X_{1n}^{t} \\ \vdots & \ddots & \vdots \\ X_{n1}^{t+1} - X_{n1}^{t} & \cdots & X_{nn}^{t+1} - X_{nn}^{t} \end{pmatrix}$$

Here, **ΔXij represents the total output change in city i caused by the final demand change in city j**, that is, the amount of industrial transfer from city j to city i during the period from time t to time t+1. In this study, the influence of imports was excluded during the calculation process, and the final demand-driven directed industrial transfer from city j to city i was calculated. Because the original table included 42 social and economic industries, this paper further calculated ΔXijs in the same way, that is, the total output change in city i caused by the final demand change in city j in the s sector, to measure the amount of industrial transfer from city j to city i in the s sector under the final demand-driven condition.

Data sources, data processing and variable description

- **Data source:** This study is based on the multi-regional input-output tables of Chinese cities at the urban scale compiled by the CEADs team in 2012, 2015, and 2017, to calculate the volume of industrial transfer between cities in the **two time periods** from 2012 to 2015 and from 2015 to 2017. The data on the connectivity level between cities comes from Baidu Index and information on China's high-speed rail lines, while the other variable data are from the "China Urban Statistical Yearbook", "China Regional Economic Statistical Yearbook", and the statistical yearbooks of each province and prefecture-level city.
- **Data processing:** (1) Due to different observation periods, the annual average processing was conducted within the observation period; (2) Prefecture-level cities with administrative division adjustments during the sample period were excluded; (3) A small amount of missing data was manually searched for or interpolated to be completed, and a large amount of missing data was excluded; (4) Urban pairs composed solely of cities themselves were excluded. The final sample covers **272 prefecture-level cities, 74,256 urban pairs, 2 sample observation periods, and a total of 148,512 observations**, which is highly representative.

Variable Description Table

Symbol	Variable	Discription
IT	Industrial Transfer	Logarithm of the industrial transfer volume from city i to city j (positive for outflow, negative for backflow)
IT_direction	Industrial Transfer Direction	Direction of industrial transfer from city i to city j (1 for outflow, 0 for backflow)
connectivity_HSR	HSR Connectivity	Annual average number of high-speed rail lines between the two cities' HSR stations
connectivity_I	Information Connectivity	Logarithm of the daily average Baidu Search Index from city i to city j
edl	Economic Development	Annual average of regional GDP per capita
ul	Urbanization	Annual average proportion of urban population at year-end
fil	Foreign Investment	Annual average ratio of foreign direct investment (FDI) to regional GDP
hcl	Human Capital	Annual average ratio of college/university enrollment to regional population
ftl	Foreign Trade	Annual average ratio of total import and export volume to regional GDP
gel	Government Expenditure	Annual average ratio of government fiscal expenditure to regional GDP

descriptive statistics

Symbol	Mean	Median	std	min	max
IT	1.952	6.173	7.607	-15.36	16.01
IT_direction	0.620	1.000	0.485	0.000	1.000
connectivity_HSR	0.023	0.000	0.182	0.000	5.000
connectivity_I	2.482	2.671	1.751	0.000	7.391
edl	5.325	4.436	3.168	1.262	17.80
ul	0.497	0.450	0.202	0.174	1.217
fil	0.112	0.053	0.148	0.000	0.736
hcl	0.019	0.010	0.025	0.001	0.124
ftl	0.185	0.073	0.294	0.001	1.695
gel	0.200	0.176	0.097	0.081	0.876

Model

To identify the impact of the level of high-speed rail and information interconnection among cities on industrial transfer, this paper employs a **multiple fixed effects model**. The basic econometric model is set as follows:

$$IT_{ijt} = \beta_0 + \beta_1 connectivity_{ijt} + \alpha_1 X_{it} + \alpha_2 X_{jt} + \mu_{ij} + \eta_t + \varepsilon_{ijt}$$

- i and j represent cities i (the city where industries are transferred out) and city j (the city where industries are transferred in);
- t represents the sample observation period (period 1 "2012-2015" and period 2 "2015-2017");
- the explained variable ITijt represents the amount of industrial transfer from city i to city j in period t;
- the core explanatory variable connectivityijt represents the level of interconnection between cities i and j (high-speed rail connection level, information connection level);
- β0 is the constant term, β1 represents the net effect of interconnection between cities on industrial transfer between cities;
- α1 and α2 respectively represent the coefficient of the control variables of city i and city j on the industrial transfer from city i to city j, εijt is the random disturbance term.
- The interaction fixed effect of the two cities (μij) and the time fixed effect (ηt) are controlled;
- The robust standard errors are uniformly clustered by city pairs to ensure the reliability of the results.

Overall Analysis of Inter-City Connectivity' s Impact on Industrial Transfer

First, analyze the overall effect of high-speed rail connectivity and information connectivity between cities on the direction of industrial transfer, to test whether city connectivity provides more possibilities for the outward transfer of urban industries. Among them, models (1) and (3) do not contain any control variables, while models (2) and (4) include control variables for cities regarding both parties.

	(1)	(2)	(3)	(4)
VARIABLES	*IT_direction*	*IT_direction*	*IT_direction*	*IT_direction*
connectivity_HSR	**0.094****	**0.142*****		
	(0.042)	(3.336)		
connectivity_I			**0.086*****	**0.107*****
			(10.795)	(13.434)
Control variable (city1)	No	Yes	No	Yes
Control variable (city2)	No	Yes	No	Yes
City 1 ×city 2 fixed effect	Yes	Yes	Yes	Yes
Period fixed effect	Yes	Yes	Yes	Yes
Observations	148,512	148,512	148,512	148,512
R-squared	0.452	0.470	0.452	0.472

- **Statistical significance:** According to the regression results, regardless of whether control variables are added or not, the regression coefficients of connectivity_HSR and connectivity_I are significant at the 5% or 1% level.
- **Economic significance:** From the results in column (2), it can be seen that for every additional high-speed railway between cities, the probability of industrial transfer from city 1 to city 2 will increase by 14.2%; from the results in column (4), it can be known that for every 1% increase in the level of information connection between cities 1 and 2, the probability of industrial transfer from city 1 to city 2 will increase by approximately 0.11%.
- **Conclusion: Both the high-speed rail connectivity and information connectivity between cities can promote the transformation of industrial connections from inbound to outbound,** which helps to enhance the willingness of industrial transfer between cities.

- **Reason Analysis:** Specifically, the two aspects respectively provide infrastructure and information conditions for the relocation of industries. The former offers explicit and fundamental support for industrial transfer, achieving **a qualitative transformation from a "barrier" to a "route"**, while the latter provides implicit information support for industrial transfer, exerting a cumulative effect of **"accumulating over time and achieving great results"**. Based on this conclusion, this article will further analyze the impact of different connection methods of cities on the scale of industrial transfer.

Overall Analysis of Inter-City Connectivity’ s Impact on Industrial Transfer

- The city-pair samples are divided into two groups for regression analysis:

"Relatively Developed → Less Developed" (along the economic gradient)

"Less Developed → Relatively Developed" (against the economic gradient)

- This division allows for a precise identification of the **asymmetric effects** of high-speed rail connectivity and information connectivity on the scale of industrial transfer between cities. Specifically, a city's economic level is measured by the **annual average GDP per capita**.

VARIABLES	(1) Down-gradient ***IT***	(2) Up-gradient ***IT***	(3) Down-gradient ***IT***	(4) Up-gradient ***IT***
connectivity_HSR	-1.079	**3.534*** **		
	(1.310)	(2.594)		
connectivity_I			**2.266*** **	**1.418*** **
			(12.427)	(8.772)
Control variable (city1)	Yes	Yes	Yes	Yes
Control variable (city2)	Yes	Yes	Yes	Yes
City 1 ×city 2 fixed effect	Yes	Yes	Yes	Yes
Period fixed effect	Yes	Yes	Yes	Yes
Observations	74,256	74,256	74,256	74,256
R-squared	0.461	0.449	0.463	0.450

- **High-speed rail (HSR) connectivity primarily exhibits a "unidirectional industrial siphon effect."** By compressing time-space costs, HSR reinforces the agglomeration advantages of economically developed cities, facilitating one-way industrial flow toward them. This leads to "industrial hollowing out" in less developed cities, marginalizing them in regional division of labor and creating a **"polarization effect."**
- In contrast, **information connectivity demonstrates a "bidirectional industrial diffusion effect."** It breaks down traditional economic barriers and fosters a complementary two-way industrial transfer pattern. Notably, information connectivity more strongly promotes industrial transfer along the economic gradient, thereby creating greater opportunities for less developed regions to attract relocated industries.

Robustness Tests

VARIABLES	(1) Down-gradient IT	(2) Up-gradient IT	(3) Down-gradient IT	(4) Up-gradient IT
connectivity_HSR	-0.731	**3.197****		
	(1.265)	(2.253)		
connectivity_I			**2.860*****	**0.543*****
			(15.619)	(3.410)
Control variable (city1)	Yes	Yes	Yes	Yes
Control variable (city2)	Yes	Yes	Yes	Yes
City 1 ×city 2 fixed effect	Yes	Yes	Yes	Yes
Period fixed effect	Yes	Yes	Yes	Yes
Observations	74,256	74,256	74,256	74,256
R-squared	0.453	0.460	0.457	0.460

VARIABLES	(1) Down-gradient *connectivity_HSR*	(2) Up-gradient *connectivity_HSR*	(3) Down-gradient *connectivity_I*	(4) Up-gradient *connectivity_I*
IT	**-8.87e-06**	**1.76e-05**	**1.31e-04**	**2.31e-04**
	(0.000)	(0.590)	(0.964)	(1.478)
Control variable (city1)	Yes	Yes	Yes	Yes
Control variable (city2)	Yes	Yes	Yes	Yes
City 1 ×city 2 fixed effect	Yes	Yes	Yes	Yes
Period fixed effect	Yes	Yes	Yes	Yes
Observations	74,256	74,256	74,256	74,256
R-squared	0.984	0.984	0.986	0.978

- First, we **alter the measurement of economic gradient.**
- The criterion for dividing economic gradients is shifted to city **population size** (measured by **permanent residents**).
- The results demonstrate that the asymmetric effects of high-speed rail and information connectivity on industrial transfer are not driven by selection bias in specific economic metrics, but rather reflect systematic disparities between cities at different development levels. This reinforces the generalizability of our findings.

- Second, **reverse causality test.**
- we conduct a reverse causality test by regressing connectivity_HSR and connectivity_I on industrial transfer (IT). The **statistically and economically insignificant** coefficients suggest no reverse causality concerns.. This indicates the absence of reverse causality issues.

Heterogeneity Analysis of Inter-City Connectivity’ s Impact on Industrial Transfer

- In the industry classification, this study categorizes:
  - ① **Labor-intensive industries** as sectors represented by "agriculture, forestry, livestock, fishery products, and related services";
  - ② **Capital-intensive industries** as sectors represented by "production and supply of electricity and heat";
  - ③ **Technology-intensive industries** as sectors represented by "information transmission, software, and IT services"
- Industries such as "real estate" and "education", which lack clear factor agglomeration characteristics or are difficult to classify by factor intensity, are excluded from categorization.

	labor intensive				capital intensive				technology intensive			
	(1)	(2)	(3)	(4)	(1)	(2)	(3)	(4)	(1)	(2)	(3)	(4)
	Down-gradient	*Up-gradient*	*Down-gradient*	*Up-gradient*	*Down-gradient*	*Up-gradient*	*Down-gradient*	*Up-gradient*	*Down-gradient*	*Up-gradient*	*Down-gradient*	*Up-gradient*
VARIABLES	***IT_labor***	***IT_labor***	***IT_labor***	***IT_labor***	***IT_capital***	***IT_capital***	***IT_capital***	***IT_capital***	***IT_tech***	***IT_tech***	***IT_tech***	***IT_tech***
connectivity_HSR	1.348	**3.941*** **			-0.821	**3.759*** **			-0.228	1.072		
	(1.187)	(3.561)			(-0.673)	(3.046)			(-0.252)	(1.025)		
connectivity_I			**0.406*** **	**-0.388*** **			**1.814*** **	**1.467*** **			**0.614*** **	**-0.031**
			(0.150)	(-2.983)			(0.165)	(9.964)			(0.115)	(-0.284)
Control variable (city1)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Control variable (city2)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
City 1 ×city 2 fixed effect	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Period fixed effect	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	74,256	74,256	74,256	74,256	74,256	74,256	74,256	74,256	74,256	74,256	74,256	74,256
R-squared	0.485	0.453	0.485	0.454	0.468	0.459	0.467	0.458	0.461	0.458	0.461	0.458

- Intercity high-speed rail (HSR) connectivity significantly promotes the agglomeration of labor-intensive and capital-intensive industries in developed cities, validating the **"core-periphery"** theory in New Economic Geography.
- In contrast, information connectivity facilitates dispersed industrial transfer: (1) It **enables less-developed regions to undertake labor-intensive industries**, fostering localized clusters; (2) **Drives bidirectional transfer of capital-intensive industries**, reinforcing regional specialization; (3) Promotes the diffusion of technology-intensive industries along economic gradients, achieving **"technology spillover".**
- This duality suggests that **infrastructure development in the digital era must align with regional strategies**: HSR networks amplify the agglomeration advantages of economically advanced cities, while information infrastructure **creates "leapfrogging opportunities" for less-developed regions.**
- Notably, transport infrastructure primarily influences the transfer of labor- and capital-intensive industries, whereas **information linkages play a unique role in driving the relocation of technology-intensive industries.**

Mechanism Analysis

To further uncover the micro-level mechanisms through which intercity connectivity influences industrial transfer, we breaks through the traditional homogeneity assumption of factor mobility. By categorizing labor, capital, and technology as either **"Transferable" or "shared" factors** based on their **spatiotemporal exclusivity**, we systematically analyze the distinct mechanisms by which different connectivity modes affect the allocation of these two types of factors.

Labor and capital are categorized as "transferable" factors.

- **Labor Transfer**
  - Achieved through cross-city migration, reflected in changes in factor intensity between city pairs.
  - Measured by the annual average ratio of employed workers to resident population *(factor_labor)*.
- **Capital Transfer**
  - Manifests as the spatial reallocation of productive investments, including fixed asset relocation and financial capital flows.
  - Measured by the annual logarithmic averages of:
    - Net fixed asset balance ***(factor_fcapital)***
    - Liquid asset balance ***(factor_ccapital).***
- **Labor-Capital Ratio (Factor Coordination)**
  - Reflects the combined effect of factors, calculated as the logarithmic annual average of capital per worker (total capital / number of employed workers).
  - Two measures:
    - Fixed capital per worker ***(factor_flc)***
    - Circulating capital per worker ***(factor_clc).***
  - Indicates the utilization intensity of capital in production.

Technology is categorized as a "shared" factor

- Inter-city knowledge spillovers and technology sharing are reflected in the accumulation of R&D innovation outcomes between paired cities. Due to the time lag in patent grants, patent application volumes are more stable, reliable, and timely indicators than granted patents. Therefore, scholars commonly use patent application counts to measure regional technological innovation levels (Liu & Xue, 2015; Li & Zheng, 2016; Lu & Li, 2023).
- This study employs the log-transformed annual average of city-level **patent applications** as the proxy variable for technology factor ***(factor_tech)***, further analyzing how different inter-city connectivity modes affect it.

Mechanism Analysis Based on "Transferable" Factor Mobility

- The transfer of the labor force occurs through cross-city migration, which is manifested as the increase or decrease in the density of factors between cities.
- It is measured by the average annual ratio of on-the-job workers to the permanent population ***(factor_labor)***.

	(1)	(2)	(3)	(4)
	Developed cities	*Less-developed cities*	*Developed cities*	*Less-developed cities*
VARIABLES	***factor_labor***	***factor_labor***	***factor_labor***	***factor_labor***
connectivity_HSR	**0.003****	4.78e-04		
	(0.001)	(0.767)		
connectivity_I			**-4.79e-04***	**0.003*****
			(-1.907)	(27.916)
Control variable (city1)	Yes	Yes	Yes	Yes
Control variable (city2)	Yes	Yes	Yes	Yes
City 1 ×city 2 fixed effect	Yes	Yes	Yes	Yes
Period fixed effect	Yes	Yes	Yes	Yes
Observations	74,256	74,256	74,256	74,256
R-squared	0.996	0.994	0.996	0.994

Mechanism Analysis at the Labor Factor Level

Statistical Results:

- **HSR connectivity** significantly increases labor factor intensity in developed cities but shows no significant effect in less-developed cities.
- **Information connectivity** exerts a significant dispersion effect on labor factor intensity in developed cities ($p < 0.1$) and a significant enhancement effect in less-developed cities ($p < 0.01$).

Mechanism Interpretation:

- **HSR Connectivity** primarily exhibits a **"siphon effect"**—developed cities leverage the time-space compression advantage of HSR to further attract labor concentration.
- **Information Connectivity** facilitates orderly labor transfer by reducing information asymmetry: (1) **Promotes labor dispersion from developed to less-developed cities.** (2) Helps less-developed cities more efficiently match labor demand, thereby optimizing interregional labor allocation.

Mechanism Analysis Based on "Transferable" Factor Mobility

These ratios reflect capital utilization intensity in production processes. Measurement of Capital Factors and Labor-Capital Ratios is as follows:

- The total stock of urban capital is measured by: (1) Fixed capital ***(factor_fcapital)***: Log of annual average net fixed asset balance; (2) Circulating capital ***(factor_ccapital)***: Log of annual average liquid asset balance
- The labor-capital ratio is calculated as: (1) Fixed capital per worker ***(factor_flc)***: Log-transformed annual average of (net fixed assets / employed workers) (2) Circulating capital per worker ***(factor_clc)***: Log-transformed annual average of (liquid assets / employed workers)

	Developed cities				*Less-developed cities*			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
VARIABLES	*factor_fcapital*	*factor_flc*	*factor_fcapital*	*factor_flc*	*factor_fcapital*	*factor_flc*	*factor_fcapital*	*factor_flc*
connectivity_HSR	**0.033*****	0.006			**-0.029***	**-0.039****		
	(0.012)	(0.426)			(-1.877)	(-2.238)		
connectivity_I			-0.002	**-0.025*****			**0.033*****	**0.038*****
			(-0.553)	(-6.506)			(10.020)	(10.147)
Control variable (city1)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Control variable (city2)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
City 1 ×city 2 fixed effect	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Period fixed effect	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	74,256	74,256	74,256	74,256	74,256	74,256	74,256	74,256
R-squared	0.995	0.990	0.995	0.990	0.994	0.988	0.994	0.988

Mechanism Analysis of Capital Factors: Fixed Assets

- **HSR connectivity** triggers a notable **"siphoning effect"** in city pairs with economic gradient disparities. While boosting the total fixed assets in developed cities, it simultaneously leads to capital depletion in less-developed cities and exacerbates their underutilization of capital. This asymmetric factor flow **reinforces the core-periphery structure.**
- **information connectivity** demonstrates a **"diffusion effect"**. It not only increases the total fixed assets in less-developed cities but also **effectively enhances capital intensity**. Concurrently, it reduces developed cities' path dependence on fixed assets, thereby breaking barriers to factor mobility and promoting efficient capital allocation.

Mechanism Analysis Based on "Transferable" Factor Mobility

These ratios reflect capital utilization intensity in production processes. Measurement of Capital Factors and Labor-Capital Ratios is as follows:

- The total stock of urban capital is measured by: (1) Fixed capital ***(factor_fcapital)***: Log of annual average net fixed asset balance; (2) Circulating capital ***(factor_ccapital)***: Log of annual average liquid asset balance
- The labor-capital ratio is calculated as: (1) Fixed capital per worker ***(factor_flc)***: Log-transformed annual average of (net fixed assets / employed workers) (2) Circulating capital per worker ***(factor_clc)***: Log-transformed annual average of (liquid assets / employed workers)

	Developed cities				*Less-developed cities*			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
VARIABLES	*factor_ccapital*	*factor_clc*	*factor_ccapital*	*factor_clc*	*factor_ccapital*	*factor_clc*	*factor_ccapital*	*factor_clc*
connectivity_HSR	0.007	-0.019			0.001	-0.008		
	(0.012)	(-1.273)			(0.089)	(-0.508)		
connectivity_I			**0.020*** **	-0.003			**0.018*** **	**0.023*** **
			(5.448)	(-0.848)			(5.588)	(5.944)
Control variable (city1)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Control variable (city2)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
City 1 ×city 2 fixed effect	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Period fixed effect	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	74,256	74,256	74,256	74,256	74,256	74,256	74,256	74,256
R-squared	0.996	0.989	0.996	0.989	0.995	0.990	0.995	0.990

Mechanism Analysis of Capital Factors: Liquid Assets

- **HSR connectivity** demonstrates no significant impact on either the total volume or intensity of liquid assets. Given the high liquidity and low geographical stickiness of liquid assets (e.g., inventory, cash), high-speed rail exerts limited influence on their cross-regional allocation.
- As shown in Columns 3 and 7, **information connectivity** significantly enhances liquid asset scale ($p<0.01$) in both developed and less-developed cities, revealing its **dual value-enhancing effect**. Column 8 further indicates that strengthened information connectivity improves asset utilization efficiency in less-developed cities. Information connectivity exhibits a dual optimization mechanism for liquid assets: (1) **Bidirectional stock optimization** (benefiting both city types); (2) **Enhanced allocation efficiency in less-developed regions**

Mechanism Analysis Based on "Shared" Factor Mobility

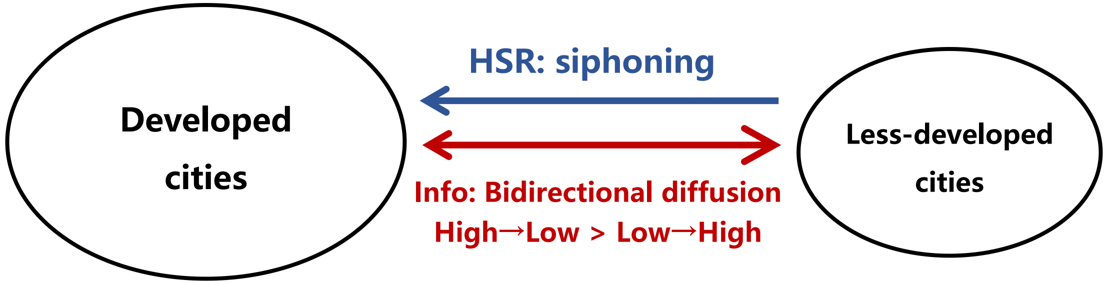
The annual average value of the number of patent applications in cities was logarithmically processed to serve as the proxy variable for the technical factor ***(factor_tech)***, and then the influence of different connection methods among cities on it was further analyzed.

	(1)	(2)	(3)	(4)
	Developed cities	*Less-developed cities*	*Developed cities*	*Less-developed cities*
VARIABLES	*factor_tech*	*factor_tech*	*factor_tech*	*factor_tech*
connectivity_HSR	-0.003	0.018		
	(0.017)	(0.923)		
connectivity_I			**0.059*****	**0.064*****
			(13.321)	(13.265)
Control variable (city1)	Yes	Yes	Yes	Yes
Control variable (city2)	Yes	Yes	Yes	Yes
City 1 ×city 2 fixed effect	Yes	Yes	Yes	Yes
Period fixed effect	Yes	Yes	Yes	Yes
Observations	74,256	74,256	74,256	74,256
R-squared	0.995	0.992	0.995	0.992

Mechanism Analysis of Technological Factors

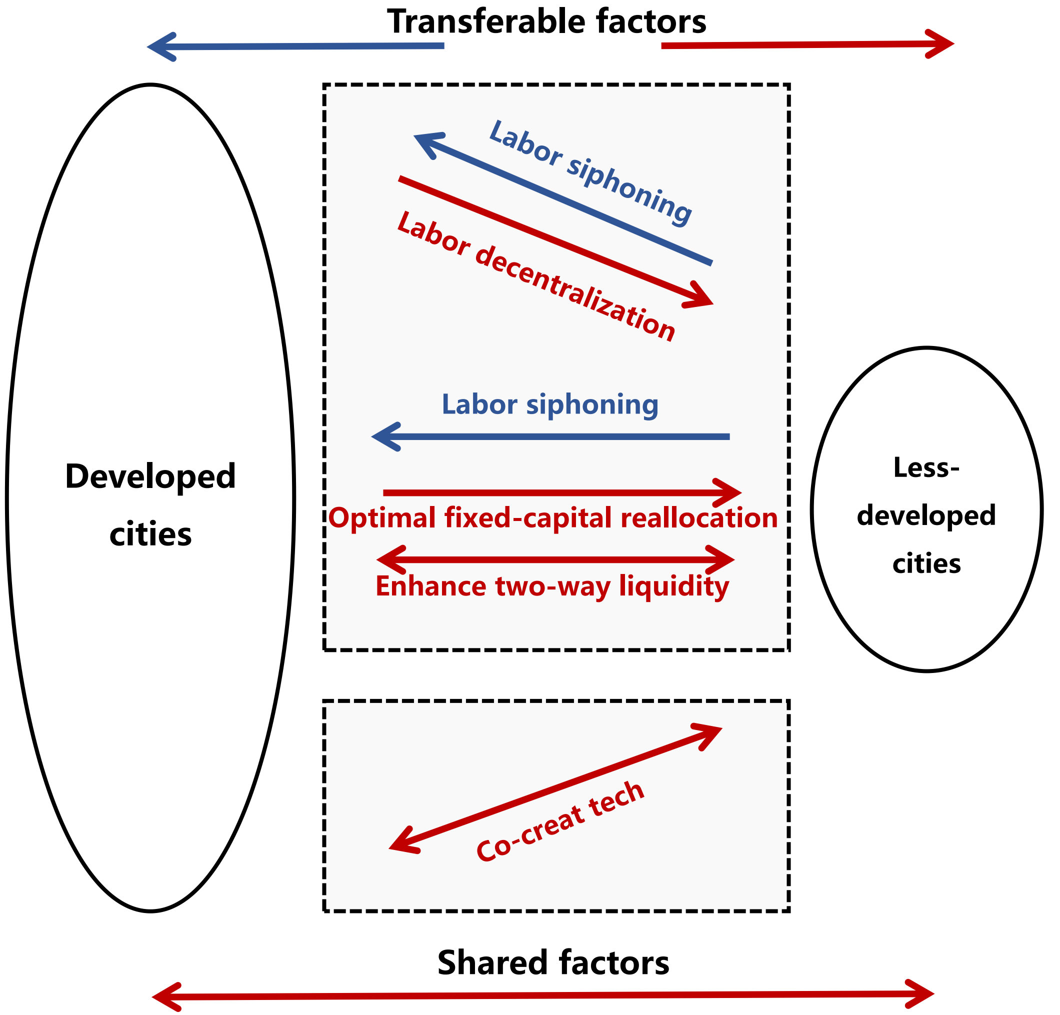
- **HSR connectivity** demonstrates no significant impact on technological factors, indicating that transportation infrastructure has limited influence on "shared" factors.
- As shown in columns (3) and (4), **information connectivity** between cities significantly enhances patent application volumes in both developed and less-developed cities ($p<0.01$). This facilitates co-creation of technological elements between connected cities and establishes a mutually beneficial, **bidirectional pathway for technological upgrading**.

Summary of the mechanism analysis results



Connectivity Type	Affected Industries	Effect Manifestation	Regional Impact
HSR Connectivity	Labor-intensive Capital-intensive	Promotes industry agglomeration in developed cities	Strengthens "core" status
Information Connectivity	Labor-intensive	Facilitates industry relocation to less-developed areas Forms local clusters	Creates development opportunities for "periphery"
	Capital-intensive	Promotes bidirectional transfer Enhances regional specialization	Optimizes inter-regional division of labor
	Technology-intensive	Spreads along economic gradient Achieves "technology spillover"	Drives technology diffusion from high to low-gradient areas

- HSR connectivity primarily drives labor-intensive and capital-intensive industry relocation, reinforcing agglomeration effects and fostering "core city" development.
- Information connectivity impacts all three industry types, particularly facilitating technology-intensive industry diffusion. It exhibits dual effects (agglomeration and diffusion) while creating opportunities for "peripheral cities."



Effect Variations of Inter-City Connectivity with Geographic Distance

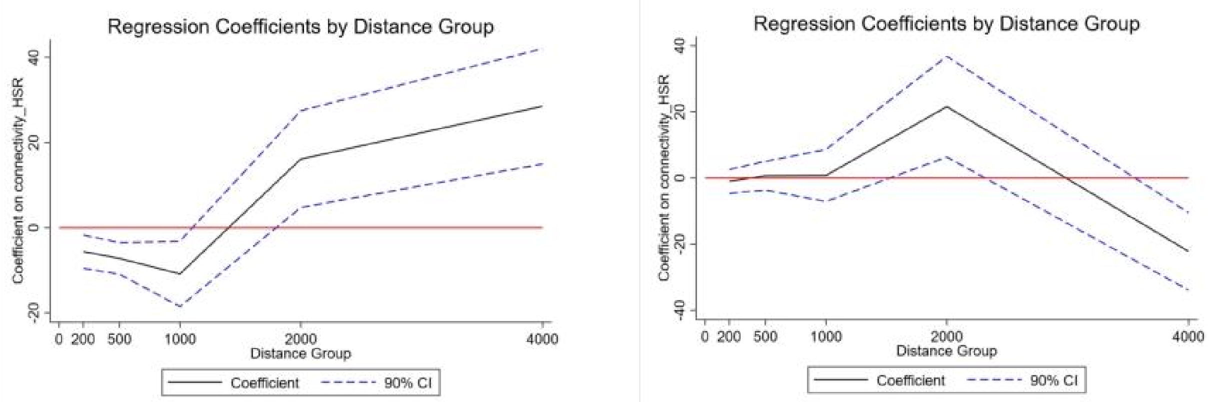
- **Theoretical Support:** The New Economic Geography highlights the pivotal role of transportation costs and information flows in shaping industrial spatial distribution, with their impact intensity on industrial transfer potentially exhibiting nonlinear changes as geographical distance increases. For cities at varying distances, the marginal utility derived from high-speed rail expansion and enhanced information connectivity differs significantly.
- **Research Significance:** Identifying the distance elasticity of these two connectivity modes can not only reveal the spatial boundaries of the "siphoning effect" and "synergistic effect," but also help determine the optimal spatial scale for cross-regional industrial collaboration. This will facilitate the development of a more efficient nationwide unified market and provide targeted policy guidance for optimizing regional infrastructure investment allocation.

Division	Distance Range	Transport Feature	Economic Linkage Characteristics	City Pair Examples
Proximal Tier	0-200 km	1-hour economic circle	Tight integration, frequent short-distance exchange	Beijing-Tianjin, Guangzhou-Foshan, Shanghai-Suzhou
Regional Tier	200-500 km	2-hour HSR access	Economic coordination within city clusters or adjacent provincial capitals	Shanghai-Nanjing, Wuhan-Changsha, Chengdu-Chongqing
Cross-Regional Tier	500-1000 km	Half-day HSR access	Typical scale for cross-regional cooperation	Beijing-Zhengzhou, Guangzhou-Wuhan
Strategic Tier	1000-2000 km	Long-distance HSR/air	East-West pairing or North-South linkage	Shanghai-Chongqing, Shenzhen-Chengdu, Hangzhou-Shenyang
Remote Tier	2000-4000 km	Ultra-long-distance HSR/air	Coastal-hinterland interaction, paired assistance	Urumqi-Shanghai, Lhasa-Guangzhou, Harbin-Kunming

- This study categorizes inter-city geographical distances into five concentric tiers using 200, 500, 1000, 2000 and 4000km as thresholds:
- Include: Proximal tier (0-200km); Regional tier (200-500km); Cross-regional tier (500-1,000km); Strategic tier (1,000-2,000km); Remote tier (2,000-4,000km)

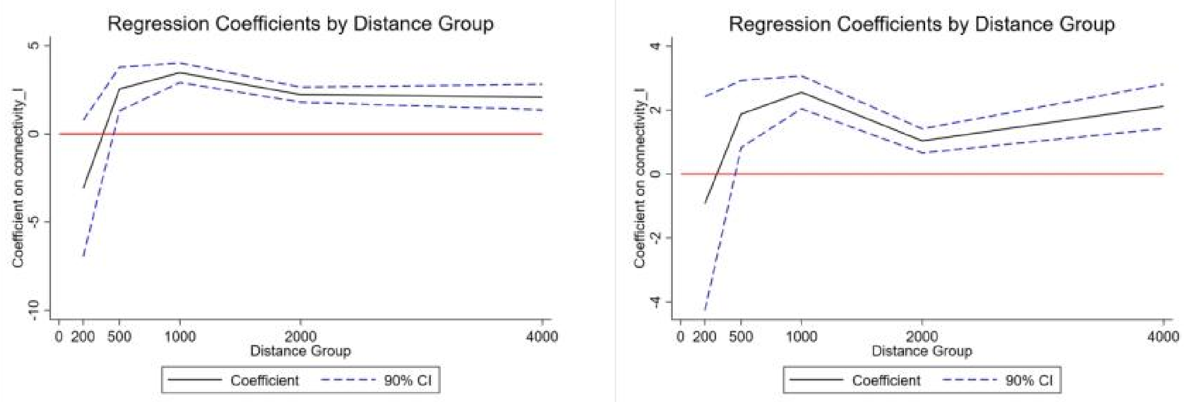
Effect Variations of Inter-City Connectivity with Geographic Distance

- This study conducts grouped regression analyses across the five geographical distance-based tiers, presenting their respective regression coefficients.
- The figure displays: (1) **X-axis:** Geographical distance tier. (2)**Y-axis:** Regression coefficients of HSR/information connectivity effects on industrial transfer scale. (3)**Blue dashed line:** Confidence intervals at 10% significance level.



a. Down-gradient b. Up-gradient

Changes in HSR Connectivity' s Impact on Industrial Transfer with Geographic Distance



a. Down-gradient b. Up-gradient

Changes in Information Connectivity' s Impact on Industrial Transfer with Geographic Distance

- **Within 1,000 km:** HSR pulls industries back to developed cities (strongest in cross-regional zones).
- **Beyond 1,000 km:** HSR shifts industries to less-developed areas (effect grows with distance).

Further analysis identifies HSR-induced industrial transfer as primarily exhibiting "agglomerative siphoning," but with boundaries:

- **Short-to-medium distance (0–1,000 km):** "Siphoning effect" (drains industries).
- **Long distance (1,000–2,000 km):** "Exchange effect" (two-way flow).
- **Very long distance (2,000+ km):** "Spillover effect" (supports less-developed areas).

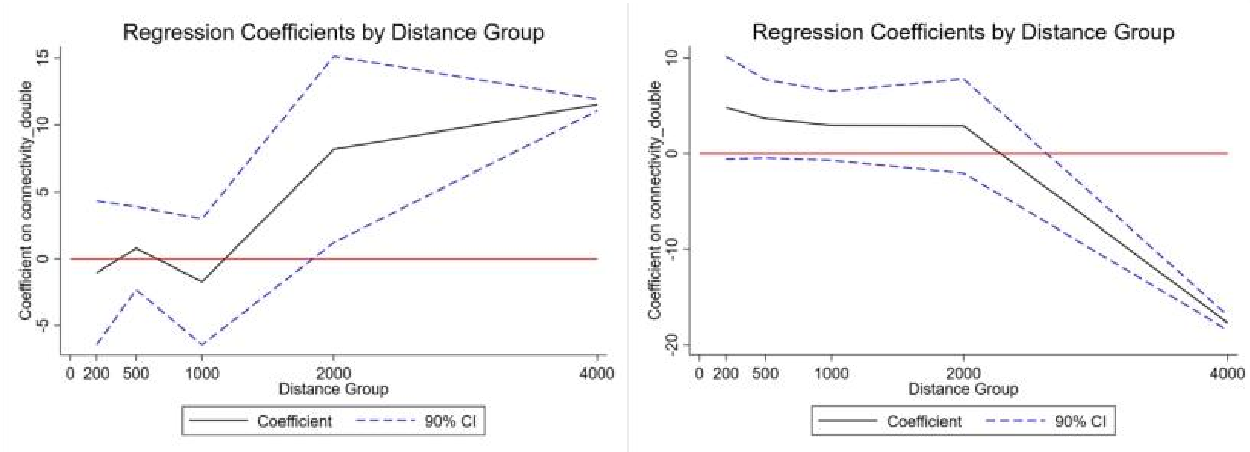
- **Proximal Zone (0-200 km):** Effect insignificant (likely due to already strong local information networks). Implication: Nearby cities in China have mature information exchange.
- **Cross-Region Zone (500-1,000 km):** Peak "two-way diffusion" effect on industrial transfer (regardless of economic gradient).
- **Beyond 1,000 km:** Effect declines (possibly due to rising logistics costs).
- **Overall Trend:**
  - Stable "two-way diffusion" effect.
  - Intensity follows an inverted U-curve with distance.

Synergistic Effects of Inter-City Connectivity with Geographic Distance

- **Heoretical Support:** As dual carriers of modern spatial interaction, traditional infrastructure (e.g., HSR) and new connectivity (e.g., digital networks) reshape industrial transfer patterns through physical accessibility and virtual mobility, respectively. Their interplay may challenge the unidimensional distance assumption in classical Core-Periphery Theory.
- **Research Significance:** With China's coordinated "Transport Powerhouse" and "Digital China" strategies, identifying synergistic modes of both connectivity types across distance tiers provides scientific support for regional policy optimization.
- **Methodology:** We introduce Model (5) to test their interaction effect:
  - Interaction term (**connectivity_double**): Product of HSR and digital connectivity levels.
  - **Key coefficient β_3**: Captures their synergistic effect on industrial transfer.

$$IT_{ijt} = \beta_0 + \beta_1 connectivity\_HSR_{ijt} + \beta_2 connectivity\_I_{ijt} + \beta_3 connectivity\_double_{ijt} + \alpha_1 X_{it} + \alpha_2 X_{jt} + \mu_{ij} + \eta_t + \varepsilon_{ijt}$$

Changes in the Synergistic Effect of HSR and Information Connectivity on Industrial Transfer with Geographic Distance



a. Down-gradient **b. Up-gradient**

- **Short-to-Medium Distances (0–1,000 km):**
  - No significant synergy between HSR and digital connectivity.
- **Long Distances (1,000+ km):**
  - **(a) Down-gradient transfer (Developed → Less-developed):**
    Synergy peaks in:
    - **Strategic tier (1,000–2,000 km):** Effect strengthens with distance.
    - **Remote tier (2,000–4,000 km):** Strongest significant synergy ($p<0.01$).
  - **(b) Up-gradient backflow (Less-developed ← Developed):**
    Remote tier (2,000–4,000 km): Highly significant reverse transfer ($p<0.05$).
- **Key Implications:**
  - **Statistical:** Synergy is overwhelmingly significant only **in Remote tier** for both gradients.
  - **Policy:** **Enables targeted "paired assistance"** in industrial transfers in ultra-distant (2,000–4,000 km) city pairs.

Research Conclusions

This study investigates the impact of high-speed rail (HSR) connectivity and information connectivity on intercity industrial transfer from the perspective of industrial gradient shifts. Using panel data on inter-prefecture city linkages in China (2012-2017), we analyze four key flows - transportation, information, production factors, and industries - through a multiple fixed-effects model approach. Our research examines the mechanisms, spatial effects, and synergistic effects of these connectivity modes. Key findings include:

- **Characteristic Analysis:**

China's industrial layout has shifted from "central collapse and coastal agglomeration" to accelerated relocation to central/western regions, with weakening distance constraints. Spatial distribution now features expanded coverage, diversified directions, and clustered recipient hubs. Improved HSR/information connectivity and emerging city-group hubs drive regional coordination.

- **Baseline Regression:**

HSR connectivity provides visible infrastructure support, enabling one-way industrial siphoning, while information connectivity offers invisible informational support, facilitating two-way diffusion. HSR attracts labor- and capital-intensive industries to developed cities, whereas information connectivity promotes local clustering of labor-intensive industries and gradient diffusion of technology-intensive ones.

- **Mechanism Analysis:**

HSR concentrates labor and capital in developed cities but fails to enhance capital intensity. Information connectivity redirects factors to less-developed areas, reduces path dependence in advanced regions, and enables technology co-creation. HSR shows no significant impact on "shared" technological factors.

- **Further Research:**

HSR's siphoning effect dominates proximal/regional tiers, shifts to bidirectional exchange in strategic tiers, and becomes directional transfer in remote tiers. Information diffusion follows an inverted U-curve, peaking in cross-regional tiers. Both synergistically enable "targeted assistance" industrial transfer in remote tiers.

Policy Proposal

Core Patterns: Although this study is based on data from 2012 to 2017 when high-speed rail and the digital economy were still in their development stages, the core patterns it reveals—that high-speed rail tends to reinforce the "siphoning effect" while information infrastructure promotes "two-way diffusion," along with the tiered differences in their synergistic effects—maintain long-term applicability.
Foresight: The current completion of the "Eight Vertical and Eight Horizontal" high-speed rail network and the rapid advancement of new infrastructure such as 5G, computing power networks, and the "East Data West Computing" project have validated the study's foresight.

- **Build a new-type interconnected infrastructure system by coordinating HSR and digital infrastructure development.**

Prioritize enhancing cross-regional information transmission capacity and expanding inclusive digital access in less-developed areas to create efficient information platforms for industrial transfer. Deeply integrate the "East Data West Computing" project with industrial relocation, guiding new infrastructure like data centers to resource-abundant regions. Through dual pillars of "hard connectivity" (transport) and "soft connectivity" (information), optimize factor circulation networks to support gradient industrial transfer.

- **Advance market-oriented reforms for production factors to eliminate mobility barriers.**

For "transferable" factors (labor, capital), improve the national unified market through hukou reform and equalized public services while enabling efficient bidirectional capital allocation. For "shared" factors (technology, data), establish robust technology trading platforms and data factor markets to facilitate remote co-creation and sharing. Institutional innovations should remove flow bottlenecks and enhance allocation efficiency.

- **Implement tiered regional strategies for coordinated development.**

In proximal tiers, intensify intercity transport/information networks to boost "R&D-manufacturing" industrial chain integration. For cross-regional tiers, upgrade HSR corridors and information backbones to align city cluster strategies. Remote tiers should focus on strategic HSR routes and inclusive digital infrastructure to strengthen "targeted assistance" collaboration, guiding directional industrial transfer and remote empowerment for balanced regional growth.

Thanks!

Welcome your comments and suggestions!

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