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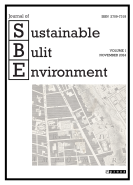

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Impact of Short-Haul High Speed Rail Commuting on Land Use and Spatial Structure in a Multi-Centre Metropolitan Area

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KEYWORDS

sustainable development,
HSR,
land use,
metropolitan area,
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land value,
short haul commuting

ABSTRACT

Owing to the enhanced accessibility afforded by high-speed rail, the relationship between megacities and their neighboring cities has grown closer. Megacities exert a significant influence on the land use of neighboring cities. This study employs a spatial econometric model to investigate the direct impact and spatial spillover effects of high-speed rail on urban land values, based on urban panel data from China's Yangtze River Delta region (2006-2020). The results revealed that shorter commuting times and improved frequency of service had a more substantial effect. Additionally, due to alterations in land values, there is a distinct preference tendency for urban land use attributes. Therefore, the city's spatial organization has transformed, and its center of gravity has shifted as well. This study provides crucial theoretical justifications and empirical evidence to fill the gaps left by previous research on the effects of short-haul high-speed rail commuting on urban housing prices and land use. The study also offers valuable insights for strategic planning and implementation aimed at promoting urban development and urban agglomeration construction through HSR construction.

1. Introduction

The Tokaido line in Japan inaugurated the High-Speed Rail (HSR) era in 1964. Since then, high-speed rail has been rapidly developed and widely used throughout the world as an effective tool and principal method of travel. By the end of 2022, there were 59,000 km of high-speed lines in operation worldwide (UIC,2023). The Beijing-Tianjin intercity high-speed railway opened on August 1, 2008, ushering China into the high-speed railway era(Hu et al., 2019). The Chinese government issued the "Four Vertical and Four Horizontal" and "Eight Vertical and Eight Horizontal" medium and long-term plans for China's high-speed railway network in 2008 and 2016, respectively, fostering the further development of high-speed rail in China (Xu et al., 2018) . The length of high-speed rail in China reached 42,000 km by 2022 (UIC,2023).

High-speed rail (HSR) is regarded as one of the most significant technological developments in transportation systems(Campos & de Rus, 2009), with significant implications for the economy, accessibility, and people mobility (Chang & Lee, 2008). The impacts of high-speed railways are most noticeable in the cities and regions along the routes (Jiang et al.,2019). However, the impact of HSR on urban growth is uneven and the resulting growth rate is variable(Zhang et al., 2022). Surprisingly, high-speed rail has not always created chances for

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growth; in certain cases, it has exacerbated urban decline (Deng et al., 2019).

Intercity commuting is encouraged by high-speed rail(L. Wang et al., 2020). HSR services within an hour of large cities promote metropolitan integration by either fostering new mobility patterns or reinforcing preexisting ones (Garmendia et al., 2011). HSR, however, does not necessarily result in regional integration. HSR promotes regional integration when it allows for a more equitable distribution of resources among regions; on the other hand, it can result in spatial polarization when it reinforces the dominance of central areas (Monzón et al., 2013). It has been stated that HSR has a redistributive effect on regional development rather than a generative one (*Economic Analysis of High Speed Rail in Europe*, 2012). Measurement of the genuine impact of inter-regional integration brought about by HSR is made possible by the large-scale development of HSR, which incorporates cities of various sizes into the system (Z. Chen & Haynes, 2017). The development of China's high-speed rail network has had a wide-ranging impact on regions and cities, influencing regional development, intercity travel, and regional integration(G. Chen & Silva, 2014). The rapid development of China's high-speed railway has brought expansion to cities along the railway.(Yu et al., 2022).

The urban expansion and urbanization of small cities brought about by HSR is not the same as that of medium and large cities, or even different from that of other small cities, since cities with HSR stations do not all currently have the same level of urbanization, the different economic composition of the cities, and the different population and resources available. It is crucial to examine the integration process and the real effects of HSR from the perspective of small cities' development in the context of regional integration in metropolitan areas.

According to the 14th Five Year Plan of the Chinese State Council, the next phase of urbanization will promote joint growth in metropolitan areas based on one-hour commutes. However, the impact of high-speed rail on urban growth is not balanced. It is therefore crucial to examine the impact of HSR services on land use diversity and urban sprawl in smaller cities around central cities. The study explores the changes in land use and the direction of development in the surrounding small cities following the introduction of the HSR. This study provides a theoretical basis for predicting the future development trend of regional integration in China's metropolitan areas. It also helps to understand the overall impact of HSR construction on regional development, as well as the impact on the land use and development focus of the surrounding small cities.

2. Literature Review

2.1. High-speed rail as a means of inter-city commuting

HSR's function in promoting labor mobility for commuting is a relatively recent phenomena that, in principle, drastically cuts the time it takes for trains to travel between cities, expanding labor markets into areas that weren't conceivable before HSR. (Vickerman, n.d.) Workers that commute between two cities seems to be motivated by regional salary disparities. The interaction of factors that affect commute decisions for HSR have mostly been examined from an economic standpoint, including regional salary discrepancies, housing rental costs, and unemployment rates. (Guirao et al., 2020) Additionally, the cost of the tickets and the length of the commute were important factors in deciding to commit to HSR commuting. (Moyano, 2016)The causes of the rise in high-speed rail commuting are multifaceted, and certain local causes are rarely acknowledged.

2.2. Impact of HSR on Land Value in Small Cities

It has been indicated that the HSR promotes economic development and population growth, and further increases the value of land(Huang & Du, 2021). The location of the HSR stations and the frequency of railway services affect to some extent the changes in land values in this city.(L. Wang et al., 2018) It has also been shown that the introduction of high speed rail has resulted in a more significant increase in land value for smaller cities. (Huang & Du, 2021) In addition, price increases are more pronounced for housing in smaller cities than in larger cities on the same railway route. (Z. Chen & Haynes, 2015)

2.3. The Impact of the HSR on Land Use Diversity in Small Cities

It was revealed that changes in land use structure existed over time.(Wang et al., 2018). Some argue that high-speed rail-based urban development has given Chinese cities the possibility of transformation (C.-L. Chen & Wei, 2013). In addition, local government land use policy largely affects social justice as it leads to social segregation and unjustified expropriation.(Ren et al., 2020).

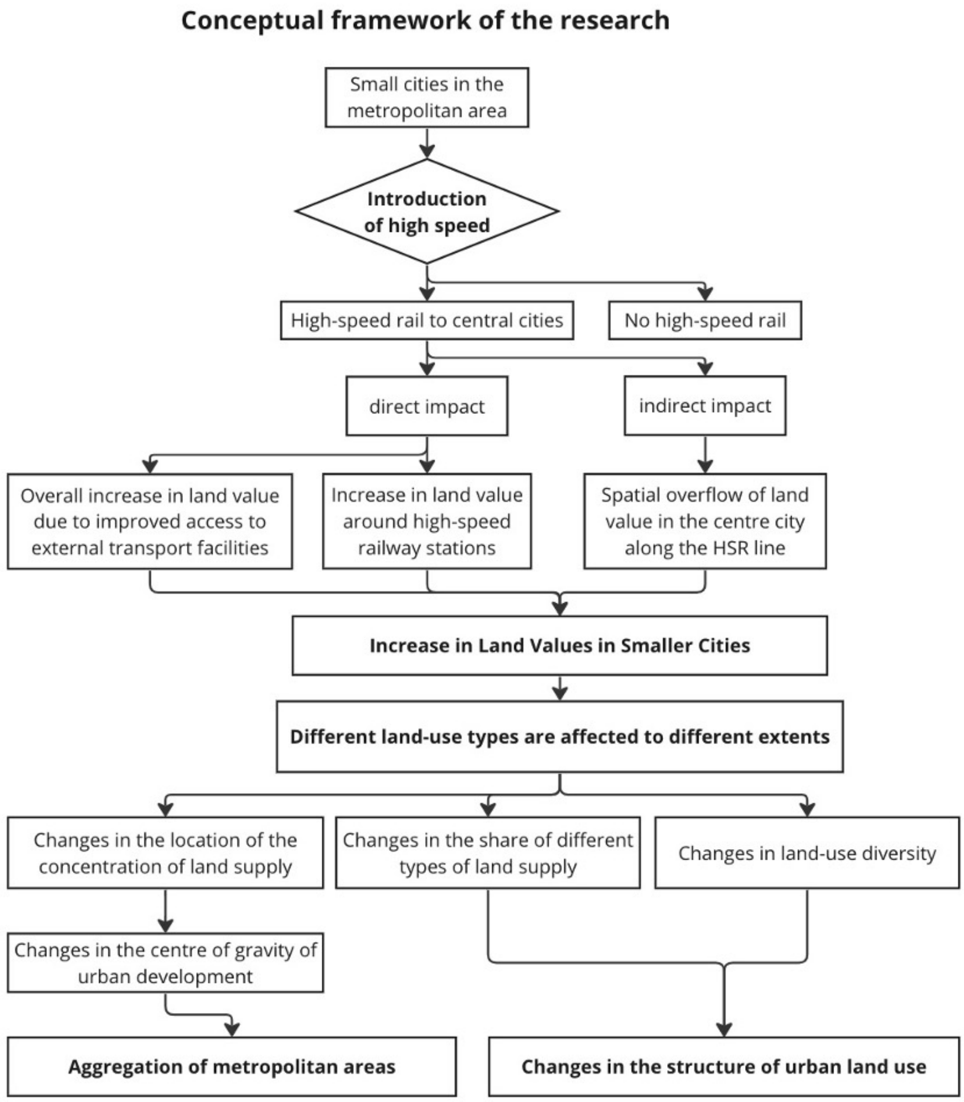

Fig. 1. Conceptual framework of the research

2.4. Impact of HSR development on urban spatial structure

HSR has been referred to be a "catalyst for the reorganization of urban systems," and it may have an impact on the surrounding metropolitan region through both agglomeration and diffusion effects. High-speed rail (HSR) stations can have a significant impact on urban development. When located in new towns, they can promote urbanization, while in old towns, they can stimulate urban regeneration(Zhu et al., 2015). Typically, the introduction of the HSR will reduce the amount of industrial land and increase the amount of commercial and logistics land, thus leading to a more diversified land use in the city (Z. Chen et al., 2021) . It has been argued that the patterns of development associated with high-speed rail (HSR) can vary depending on factors such as city size and available resources(Zhu et al., 2015).

In conclusion, while the impact of High-Speed Rail (HSR) on urban land use and spatial structure has been extensively studied, the majority of research has focused on large cities, with only a few examining the impact of HSR on smaller cities. Furthermore, the impact of HSR on urban development varies according to the frequency of service, yet few studies have looked at the impact of HSR from a higher frequency of service. This article fills a gap in research by analyzing the impact of short-haul HSR on land use and spatial structure in small cities within metropolitan areas, particularly in China's Yangtze River Delta. The study investigates changes in land use and growth direction following the installation of HSR, adding to our understanding of the overall impact of HSR construction on regional growth and its economic, social, and environmental implications. It closes a gap in prior studies of this type.

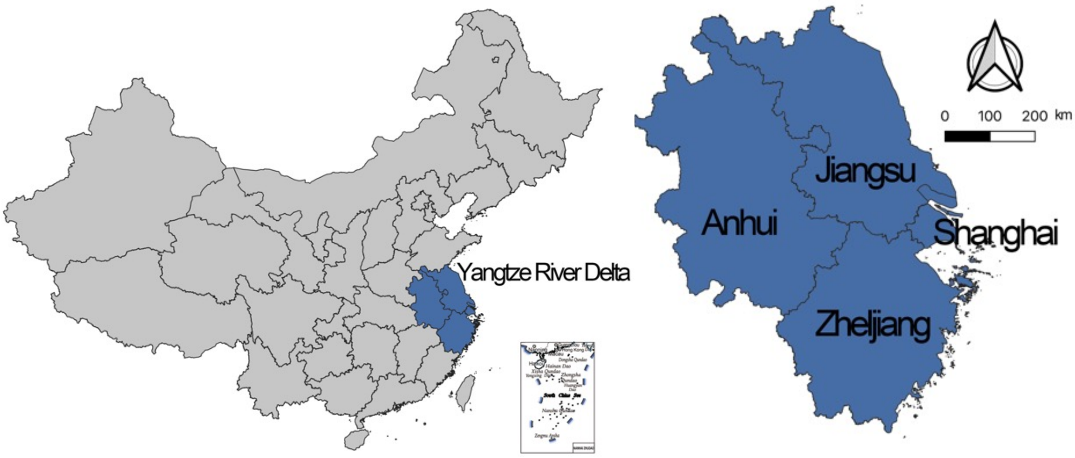

Fig. 2. Location of study area

3. Study area

The Yangtze River Delta on China's east coast was chosen as the subject location for this work. Jiangsu, Zhejiang, Anhui, and Shanghai are the three provinces and one municipality immediately under the Central Government. The Yangtze River Delta region has a total size of 358,000 square kilometers, a population of 237 million people, and a GDP of RMB 29.03 trillion in 2022. In 2019, the Yangtze River Delta's railway network density reaches 325 km per 10,000 sq km, which is 2.2 times the national average. The Yangtze River Delta will have 13,749.7 kilometers of railways by the end of 2022, including more than 6,700 kilometers of high-speed railways. The Yangtze River Delta, being one of China's most developed urban areas, has the most high-speed rail lines and the most extensive high-speed rail development. As a result, the Yangtze River Delta would be the greatest study area to investigate the influence of HSR services on land use diversity and urban sprawl in smaller cities around major cities.

4. Data and Methodology

4.1. Data sources

4.1.1. Frequency of HSR services

The frequency of HSR services (average commute time and daily departures) indicates the closeness of the city (including district, county, and town) to the central city in terms of HSR transport connections. A greater frequency of HSR services can efficiently facilitate people's mobility between cities. This data was obtained from the official website of the Ministry of Railways (www.12306.cn)

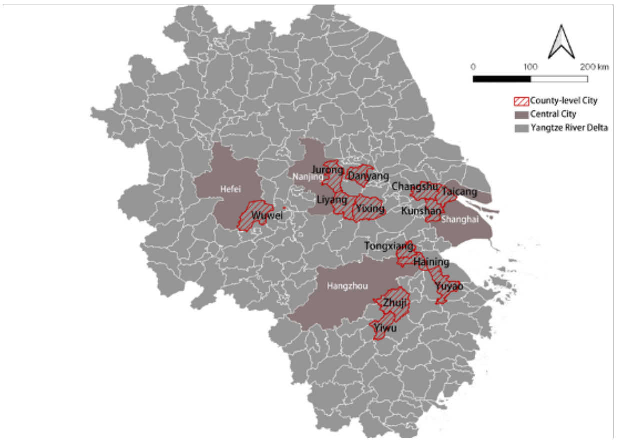

Fig. 3. Location of selected county-level cities

4.1.2. County-level Cities

In China's administrative levels, county-level cities are the smallest. In the Yangtze River Delta, there are 50 county-level cities, 21 of which are in Jiangsu Province, 20 in Zhejiang Province, and 9 in Anhui Province. 31 of these county-level cities have high-speed rail stations. Among them, 15 county-level cities are less than an hour by high-speed rail from any of the central cities, namely Shanghai, Nanjing, Hangzhou, and Hefei. These are Kunshan, Danyang, Taicang, Changshu, Jurong, Liyang, Yixing, Tongxiang, Haining, Yuyao, Zhuji, Yiwu, Jiande, Chaohu, and Wuwei. Among them, Chaohu and Jiande are under the management of the central city, so they were removed from the dataset to avoid errors caused by the difference in administrative levels. Data sources are the websites of the Chinese central government (www.gov.cn) and the Ministry of Railways (www.12306.cn).

4.1.3. Spatial distribution of urban land

This study diverges from traditional land use research that relies on remote sensing data. Instead, it employs land transaction data obtained from the Land Market of China website (www.landchina.-com) to analyze changes in urban land use structure. The website offers a comprehensive repository of information pertaining to transactions involving all released land by local governments. This includes, but is not limited to, details such as the address, intended land use, area size, land source, leasing pattern, and land use type. Unlike conventional data sources, land transaction data not only reflects land use during urban growth but also provides insights into land values and transaction sizes. This information is particularly valuable for understanding the evolving development goals of small cities. Additionally, the dataset offers greater spatial and temporal precision in tracking changes in land use and is better suited for capturing the dynamic nature of structural changes in land use.

A web-crawling technique was employed to collect information on 2.75 million registered detailed land transactions from 2000 to 2022, following the methodology established by Chen (Z. Chen, 2017). The data encompassed three types of land transactions: free transfer, negotiation, and public tender, auction, and listing. The raw data included 63 different land types. A systematic approach was applied to clean, filter, process, and validate the raw data. The refined data were then consolidated into a standard panel dataset comprising 38,914 records of land transactions for 15 county-level cities between 2006 and 2020. Land use classification criteria are shown in Appendix Table A1.

4.2. Methodology

4.2.1. Land use information entropy

In accordance with the methodologies employed by Manaugh and Kreider (2013), we utilized the entropy index as a means of quantifying changes in land use structure. In essence, the concept of land use information entropy can be expressed as follows:

$$H_{j,t} = -\sum_{i=1}^{n} P_{i,j,t} \cdot \ln P_{i,j,t}$$

In this context, $H_{j,t}$ represents the land use information entropy within city j during year t. The variable $P_{i,j,t}$ denotes the proportion of land use type i within city j during year t, while n signifies the total number of land types. The larger the land use information entropy index, the higher the diversity of the land use structure.

4.2.2. Spatial autocorrelation regression (spatial Durbin model)

Considering the spillover effects in land use studies, the Spatial Durbin Model (SDM) was used in this analysis. The Spatial Durbin Model, as an unconstrained model, can in some cases degenerate into a Spatial Lag Model and a Spatial Error Model(Pace, 2009). The SDM is represented as follows:

Table 1. Number of daily departures and average commuting time of county-level cities to central cities

	Shanghai		Nanjing		Hangzhou		Hefei	
	Average (min)	Departures (times)	Average (min)	Departures (times)	Average (min)	Departures (times)	Average (min)	Departures (times)
Kunshan	22	137	115	120	96	30	185	40
Taicang	34	54	199	5	108	7	238	3
Tongxiang	43	31	160	12	19	31	230	4
Changshu	55	44	177	6	133	4	214	6
Jurong	0	0	13	9	75	8	72	2
Danyang	89	75	41	60	176	8	123	19
Yixing	135	2	43	74	43	66	103	23
Liyang	145	1	33	35	55	38	93	10
Haining	75	54	260	16	31	62	244	1
Yiwu	97	39	148	27	35	82	198	8
Yuyao	119	33	188	27	46	91	276	21
Zhuji	124	35	206	13	35	63	268	7
Wuwei	0	0	106	1	0	0	37	20

$$Y = \rho W Y + \alpha + X\beta_1 + \theta W X\beta_2 + \varepsilon$$

In this equation, WY expressed as a linear combination of the land use index variables derived from neighboring observations, with *W* being an inverse distance matrix. *X* refers to the independent variables, while *WX* denotes a matrix of spatially lagged independent variables.

In order to accurately capture the spatial dependence and regional characteristics of changes in land use structure, this study employs a Spatial Durbin Model that takes into account following key attributes:

GDP per capita (pergdp)：An increase in GDP per capita is often associated with shifts in the urban land use structure, such as accelerated urbanization and a heightened demand for commercial and residential land, among other changes. It has been argued that changes in per capita GDP are driving land use shifts in China (He et al., 2014).

High Speed Rail Service Frequency (HSRFRE): High Speed Rail Service Frequency is an indicator of the connectivity between small and large cities via high-speed rail. It is calculated as the ratio of the average journey length to the number of daily departures. A lower ratio indicates a higher frequency of service, implying more intensive connectivity between the city and the central city via high-speed rail.

Fiscal deficit (fd): Since local governments have to hand over 60% of their tax revenue to the central government, the remaining tax revenue is often insufficient to support fiscal expenditure. As a result, many local governments tend to sell more land to generate fiscal revenue(Ding, 2007). Changes in the structure of urban land use are often accompanied by changes in the policy preferences of local governments.

Rate of urbanization (ur): The rate of urbanization is widely recognized as a major factor in land use change(Ho & Lin, 2004). Urbanization affects the land use structure of a city as it involves converting non-urban land to urban uses. This leads to increased demand for housing, infrastructure, and services, resulting in the development of previously undeveloped land or redevelopment of existing land. Urbanization can also indirectly affect land use by attracting new businesses and industries, leading to changes in the economic structure of the city and land use patterns.

Population density (pd): Population density is closely related to land use patterns (J. Lu & Guldmann, 2012). An increase in population density can increase the demand for land, while also changing the attributes of land use.

4.2.3. weighted centre of gravity analysis (WCGA)

Weighted Centre of Gravity Analysis (WCGA) is a method used in urban economics to analyze the spatial distribution of economic activity. It is based on the concept of the center of gravity, which represents the average location of economic activity across a given geographic area. In the context of urban economics, WCGA can be used to study the dynamics of urban expansion and the driving forces behind it.

One application of WCGA in urban economics is the analysis of urban expansion patterns and their driving forces. For example, it is used in combination with a geographically and temporally weighted regression (GTWR) model to study the urban expansion patterns of the Beijing-Tianjin-Hebei urban agglomeration(H. Wang et al., 2020). The study revealed the multi-dimensional characteristics of urban expansion patterns and analyzed the driving forces behind them using the center of gravity-GTWR model.

Another application of WCGA in urban economics is the analysis of spatial network structures of urban agglomerations. It is used an improved gravity model to analyze the structure of city networks in two urban agglomerations in China(Zhao et al., 2021). The study improved upon traditional spatial gravity models by considering factors such as city quality, gravitation coefficient, and city distance, and applied the improved model to analyze the spatial network structures of the Beijing-Tianjin-Hebei and Yangtze River Delta urban agglomerations.

In summary, WCGA is a valuable tool for analyzing the spatial distribution of economic activity in urban economics. It can be used in combination with other methods, such as GTWR and gravity models, to provide insights into the dynamics of urban expansion and the spatial network structures of urban agglomerations.

5. Results and Discussion

5.1. Impact of HSR on Land Value in Small Cities

The preliminary analysis of the impact of High-Speed Rail (HSR) on land values in small cities within the Yangtze River Delta (YRD) region indicates that the presence of HSR has a significant positive effect on land value growth. Specifically, small cities with HSR connections experienced

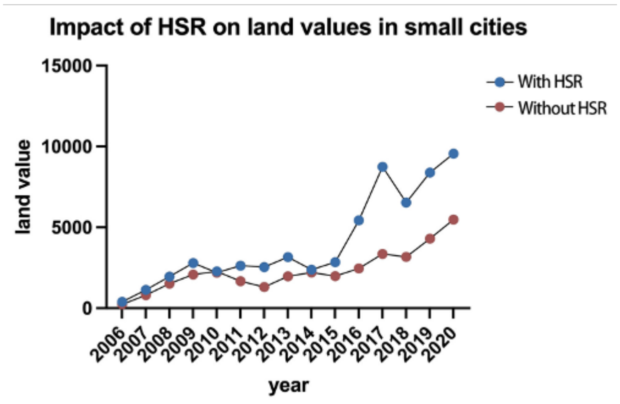

Fig. 4. Impact of HSR on land values in small cities

faster growth in land values compared to those without HSR. Furthermore, the analysis suggests that the frequency of HSR service is positively correlated with the rate of land value growth. This means that small cities with more frequent HSR service experienced faster growth in land values than those with less frequent service. These findings highlight the potential economic benefits of HSR infrastructure for small cities in the YRD region.

The potential economic benefits of HSR infrastructure for small cities in the YRD region are significant. Improved connectivity can help to attract investment and development, leading to increased economic activity and growth. This can have a positive impact on land values, as demand for land increases in response to increased economic activity. The analysis suggests that small cities with HSR connections are well-positioned to benefit from these economic opportunities, as they have experienced faster growth in land values compared to those without HSR..

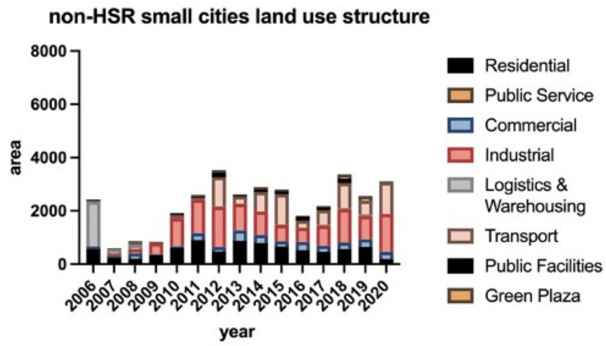

Fig. 5. non-HSR small cities land use structure

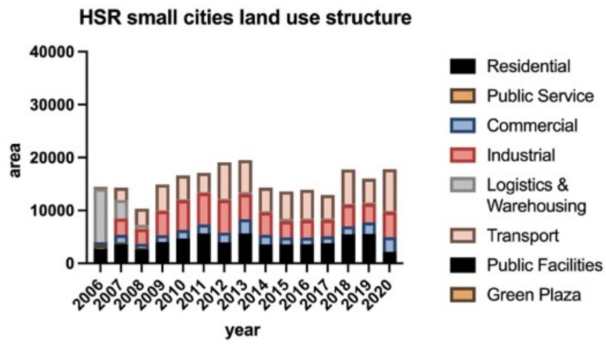

Fig. 6. non-HSR small cities land use structure

5.2. The Impact of the HSR on Land Use Diversity in Small Cities

The preliminary analysis of the land use structure of small cities with and without High-Speed Rail (HSR) reveals notable differences in the diversity and evolution of land use patterns. Small cities with HSR connections exhibit more pronounced changes in their land use structure over time compared to those without HSR. The diversity of land use in small cities with HSR appears to have improved,

Table 2. Descriptive statistics of spatial autoregressive models of land use information entropy

Variable	Obs	Mean	Std. dev.	Min	Max
year	225	2013	4.330127	2006	2020
city	0				
lue_z	225	-0.0002726	0.2989157	-0.9718732	0.6556708
pergdp_z	225	-0.0019216	1.003111	-1.81521	3.616869
hsrfre_z	225	-5.89E-09	1	-0.4395647	4.050855
fd_z	225	-0.0007852	0.9978349	-4.591957	3.391968
ur_z	225	-0.6085371	1.307252	-2.217284	2.810432
il_z	225	-0.2922183	1.02739	-1.278384	2.920457
pd_z	225	-0.0441192	1.044899	-2.657069	2.293514

with an increase in the supply of land for various uses.

Land use patterns are an important indicator of urban development and growth. They reflect the ways in which urban space is allocated and used, and they provide insight into the economic, social, and environmental characteristics of a city. The analysis suggests that small cities with HSR connections have experienced more dynamic changes in their land use patterns compared to those without HSR. This may be due to the improved connectivity provided by HSR, which can facilitate the development of a more diverse range of land uses.

The preliminary results of a spatial autoregressive analysis derived from a spatial Durbin model using the inverse distance matrix indicate that several factors have a significant impact on the land use structure of small cities surrounding large cities. Specifically, the frequency of high-speed rail service, GDP per capita, urbanization rate, fiscal deficit, and infrastructure level were all found to be significant predictors of land use structure.

These findings suggest that a range of economic, demographic, and infrastructural factors can influence the land use patterns of small cities. The frequency of high-speed rail service was found to be a significant predictor of land use structure, indicating that improved connectivity provided by high-speed rail can facilitate the development of a more diverse range of land uses. Other factors such as GDP per capita, urbanization rate, fiscal deficit, and infrastructure level were also found to be significant predictors.

These results highlight the complex interplay between economic, demographic, and infrastructural factors in shaping the urban landscape. Further research is needed to fully understand the mechanisms through which these factors influence land use patterns and to develop effective planning strategies to maximize their potential benefits.

5.3. Impact of HSR on the center of gravity of urban development

The analysis indicates that the development of high-speed rail infrastructure has significantly influenced the expansion rate of small cities. The advancement of high-speed rail has led to accelerated growth and expansion in small cities. However, it is noteworthy that the direction of expansion in small cities does not always gravitate towards neighboring centers. Instead, a novel convergence of metropolitan areas is emerging.

The improved connectivity provided by high-speed rail can facilitate the development of new

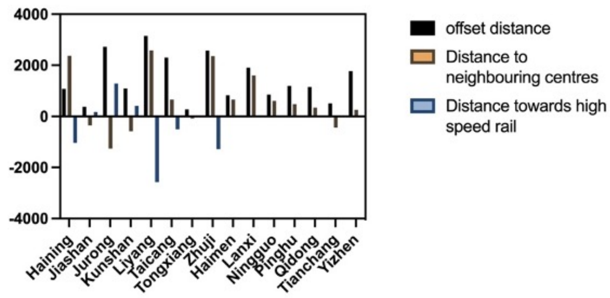

Fig. 7. Distance of Movement of the Center of Gravity in Small City Development

Table 3. Spatial Durbin Model (SDM) Autoregressive analysis results

	(1) Coff.	T-Stat
Main		
perGDP_z	0.134**	(2.824)
HSRFRE_z	-0.0788**	(-3.250)
FD_z	-0.0814**	(-3.099)
UR_z	-0.0297	(-1.331)
IL_z	0.0818**	(2.998)
PD_z	0.00321	(0.083)
Wx		
perGDP_z	0.0571	(0.635)
HSRFRE_z	-0.103*	(-2.192)
FD_z	-0.186***	(-3.525)
UR_z	0.0321	(0.715)
IL_z	0.0753	(1.457)
PD_z	0.0881	(1.062)
Spatial		
rho	-0.283***	(-3.523)
Variance		
sigma2_e	0.0263***	(10.475)
LR_Direct		
perGDP_z	0.134**	(2.826)
HSRFRE_z	-0.0716**	(-3.075)
FD_z	-0.0637*	(-2.509)
UR_z	-0.0338	(-1.551)
IL_z	0.0767**	(2.973)
PD_z	-0.00321	(-0.085)
LR_Indirect		
perGDP_z	0.0158	(0.202)
HSRFRE_z	-0.0716	(-1.759)
FD_z	-0.140**	(-3.124)
UR_z	0.0375	(1.009)
IL_z	0.0439	(1.001)
PD_z	0.0813	(1.105)
LR_Total		
perGDP_z	0.150	(1.579)
HSRFRE_z	-0.143**	(-3.155)
FD_z	-0.204***	(-4.120)
UR_z	0.00369	(0.083)
IL_z	0.121*	(2.508)
PD_z	0.0781	(0.926)
N	225	
R^2	0.064	

t statistics in parentheses
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

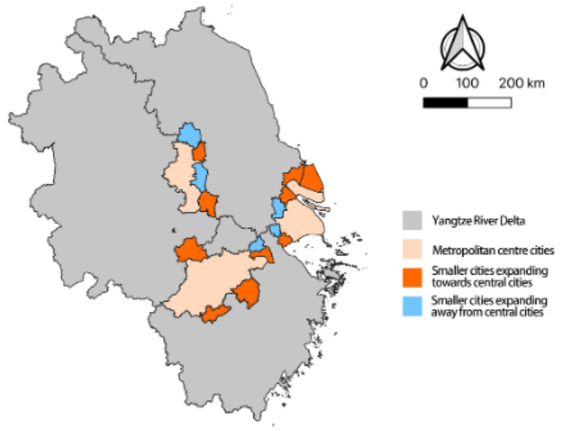

Fig. 8. Integration trends in multi-center metropolitan areas

urban centers and promote more dynamic changes in the urban landscape. This can lead to the emergence of novel convergence patterns, where urban areas grow and expand in new directions. These findings underscore the complex and dynamic nature of urban growth and expansion in the context of high-speed rail development.

In addition to its impact on the rate and direction of urban expansion, high-speed rail can also influence the land use patterns and economic structure of small cities. The presence of high-speed rail infrastructure can facilitate the development of a more diverse range of land uses, as well as promote more dynamic changes in the urban landscape. This can have significant implications for urban planning and development, as well as for the economic competitiveness and sustainability of small cities.

6. Conclusions

The research findings suggest that shorter commuting times and more frequent services have a substantial impact on urban development. A clear trend of preference for urban land use attributes is evident due to changes in land values, resulting in an increase in the diversity of land use in small cities within the metropolitan area. Concurrently, the spatial structure of cities has undergone changes, with the focus of urban development shifting in relative direction and distance.

Due to the varying attractiveness of neighboring central cities, the development focus of small cities appears to gravitate towards different neighboring cities. This is not always towards the central city, but in some cases towards neighboring medium-sized cities. This reflects the actual process of regional integration.

In summary, the research indicates that high-speed rail infrastructure can have a significant impact on the land use patterns and spatial structure of small cities. The improved connectivity provided by high-speed rail can facilitate the development of a more diverse range of land uses and promote more dynamic changes in the urban landscape. Further research is needed to fully understand the mechanisms through which high-speed rail influences urban development and to develop effective planning strategies to maximize its potential benefits.

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Appendices

Table A 1. Land use classification criteria

Primary classifications		Secondary classifications	
Number	Type	Number	Type
1	Cultivated land	11	Paddy field
		12	Dry land
2	Woodland	21	Forest land
		22	Shrub land
		23	Open forest land
		24	Other woodland
3	Grassland	31	High-coverage grassland
		32	Moderate-coverage grassland
		33	Low-coverage grassland
4	Waters	41	Graff
		42	Lake
		43	Reservoir
		44	Glacier permanent snow
		45	Sea beach
		46	Beach
5	Urban and rural areas, industrial and mining, residential land	51	Town
		52	Rural residential
		53	Public transportation land
6	Unutilized land	61	Sandy land
		62	Gobi
		63	Saline land
		64	Marshland
		65	Bare land
		66	Bare rock gravel
		67	Other unutilized land