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Spatial Impact of High-speed Railway on the Urban Scale: An Empirical Analysis from Northeast China

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Abstract: The emergence of rapid transit, primarily represented by high-speed railway (HSR), while reshaping the regional traffic patterns, leads to the reconstruction and redistribution of population and industry. This leads to either shrinkage or expansion of urban scale. However, research on the influence mechanisms of the urban scale has mostly concentrated on historical, economic and social factors. The influence of traffic factors is rarely mentioned in current research. Therefore, this study examines Northeast China, where the change in urban scale is most significant, to discuss the spatial impact of high-speed railway on the urban scale. This is of great significance in terms of enriching current understanding of the factors affecting the urban scale. The results included the following: 1) The high-speed railway produced considerable space-time convergence effects, however, simultaneously aggravated the imbalance in traffic development in Northeast China. The increase in accessibility presents attenuation characteristics from the high-speed railway. Additionally, the high-speed railway has changed the mode of cooperation between cities in the provinces, inter-regional and inter-provincial cooperation models gradually become popular. 2) The change rate of accessibility and the urban scale present significant spatial coupling phenomena, with the change rate of the Harbin-Dalian trunk lines and its surroundings being more significant. 3) There are predominantly four modes of the influence of high-speed railway on the urban scale, which make difference city present expansion or shrinkage.

Keywords: high-speed railway; urban scale; traffic accessibility; spatial coupling; GWR model

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1 Introduction

Population flow across regions is a precondition for changes in urban scale and the change in the population's spatial distribution is directly impacted on the urban scale. Transportation will inevitably affect population flow. Especially in the era of high-speed railway in China, the space-time convergence effect produced by high-speed railway constantly affects the spatial distribution of population and industry. The diffusion and agglomeration effects in turn change the urban scale (Deng et al., 2019). High-speed railway is one of the important causes of the current change in the urban scale. However, there are relatively few related studies that have been conducted on this issue to date.

With the increasing urbanization and industrialization, urban scale in China is constantly changing. Sustained urban expansion has given birth to mega-cities such as Beijing, Shanghai, Guangzhou, Shenzhen, as well as Tianjin (You and Yang, 2017). A variety of urban construction activities in China have also highlighted urban expansion to urban geography scholars and urban planning scholars. The relevant literature, for instance, has mainly focused on the following aspects: expansion

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forms, expansion modes, dynamic mechanisms, and simulation prediction. Among these, the study of expansion forms has evolved from the qualitative induction of urban space (Hossain and Sugiyama, 2011; Yan and Huang, 2013) to the quantitative measure of urban expansion boundaries (Long et al., 2009). Research into urban expansion models (Couch and Karecha, 2006) mainly focused on the patterns of urban expansion (compact/distribution), directional change (Yin et al., 2018), expansion processes (Harvey, 1978), and land use structure changes (Wang et al., 2018). The study of dynamic mechanisms can be divided into multiple factor research and single factor research (Li et al., 2018a). Research methods were mainly based on factor analysis, cluster analysis, multiple regression analysis, correlation analysis, and other statistical analysis methods. The factors mainly focused on administrative power, market power, outward force, and internal cohesion (Stern et al., 1992). The simulation prediction of urban expansion was mainly based on the application of economic measurement models. Among them were cellular automaton models, the multi-agent model and system dynamics, which have been most commonly used recently (Li et al., 2018b).

However, the overlapping effects of sub-urbanization, de-industrialization, globalization, local financial crises, and social transformation have led to the emergence of 'empty cities' and 'ghost towns' (Turok and Mykhnenko, 2007; Kabisch et al., 2010). Studies found that from 2007 to 2016, nearly 84 cities in China were experiencing urban shrinkage. Unfortunately, urban shrinkage in Northeast China was most serious and presented in a patchy distribution (Wu and Sun, 2017). Compared with urban expansion, researches related to urban shrinkage are relatively sparse. These researches mainly focus on the following aspects: 1) The spatial distribution and quantitative measurement of urban shrinkage. In terms of spatial distribution, urban shrinkage tends to spread from local to global (Mykhnenko and Turok, 2008), and from the European and American countries to parts of cities in Asia and Africa (Martinez-Fernandez et al., 2012). In terms of quantitative measurement, the predominant indicators used included aspects of social and economic indicators, spatial statistical indicators, and geospatial and landscape indicators (Reis et al., 2016). The measurement methods used are constantly improving. 2) The classification of urban shrinkage forms. At an urban level, urban shrinkage can be divided into perforated and doughnut forms, according to the spatial distribution of the population and the vacant housing facilities (Schetke and Haase, 2008). At a regional level, urban shrinkage often presents as attachment shrinkage associated with the dependence of marginal cities on core cities (Wu et al., 2015). 3) The research on the dynamic mechanisms of urban shrinkage is mainly carried out from two aspects. The theoretical aspects appeal to scholars mainly from the product life cycle, urban life cycle, business cycle theory, urbanization stage theory, new Marxist urban theory, and other perspectives. It is considered that urban shrinkage motivation is mainly caused by 'population movement' and 'capital movement' (Bontje, 2004; Harvey,1978). The econometric analysis shows that urban shrinkage is not only related to the social economy, which especially involves population and industry, but also to globalization, especially financial crisis has become obvious and irreversible in recent years.

In summary, previous studies have explored the factors affecting urban scale based on economic and social factors such as governments, markets, and the global environment, ignoring the traffic factors. However, the urban scale is the result of multiple factors such as historical, economic, societal, and transportation factors, most of which are tremendously different in each period. At present, China is in a period of rapid traffic, until 2015, 'four vertical and four horizontal' high-speed railway network was initially built (Jiao et al., 2017), and it is popular among travelers for its fast, punctual and stable characteristics. First, after the opening of high-speed railway, the accessibility of each city is increased dramatically, producing significant space-time convergence effects which affects the migration of urban population, commercial cooperation and industrial transfer (Jiao et al., 2014). In turn, flows of people, capital, information, technology, *etc*. between cities are becoming more and more significant in the process of urbanization(Yang et al., 2018; Yang et al., 2019), which, for example, can affect the change in the scale of economy, population, land use, and labor of cities. In this way, it is reasonable that elements flow will ultimately change the urban scale as well as the main spatial structure of China (Fig. 1).

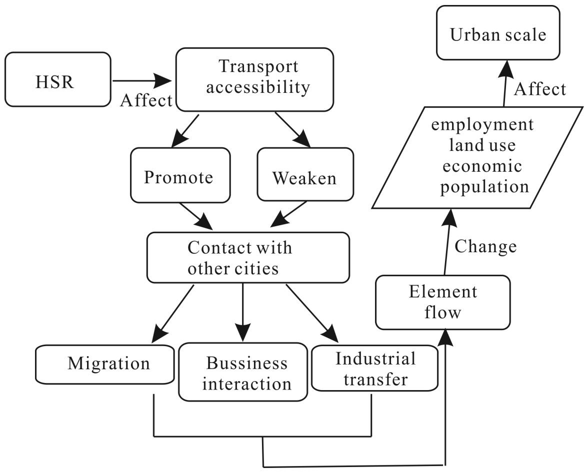

Fig. 1 The impact of high-speed railway on urban scale

What should be especially mentioned during such a dramatic transformation is the impact of traffic on the urban scale. Based on this, the present study takes Northeast China, where the changes in urban scale has been significant in recent years, as a test subject. In order to better explore the impact of the high-speed railway on the urban scale, the article first explores the space-time compression effect of high-speed railway on cities in Northeast China based on the traffic accessibility model. Based on it, the GWR model is used to reveal the spatial differentiation characteristics of the influence of high-speed railway on the urban scale.

2 Methods and Data

2.1 Methods

2.1.1 Accessibility model

Accessibility is an important index to measure traffic network structure and distribution. The most significant impact of the high-speed railway on urban development is the accessibility change (Park and Ha, 2006). The measurement methods used for accessibility includes weighted average travel time, economic potential, and daily accessibility (Gutiérrez, 2001). Accessibility is generally considered to include travel costs and location attractiveness. This paper draws lessons from the existing methods of accessibility measurement (Guo et al., 2016; Wang et al., 2019; Cao et al., 2019).

The accessibility between the original city (j) and the destination city (i) is divided into three sections: the travel time between the original city and the destination city, the time consumed in the destination city and the original city. The formula is as follows:

$$T_{ij} = t_{ij} + t_i + t_j$$
$$t_i = 15 \times \log(p_i \times 10) \qquad (1)$$
$$t_j = 15 \times \log(p_j \times 10)$$

where T_{ij} is the total traffic accessibility between city i and city j; t_{ij} is the time spent between the stations of the city j and the city i, t_i and t_j is the time spent from the home or hotel to the station in the city i and city j, based on the past research (Gutiérrez, 2001), these indicators is related to the number of people in the city. p_i and p_j represents the population size of the city i and city j, their relationships as the Formula (1).

$$T_i = \frac{\sum_{j=1}^{n} T_{ij}}{n} \qquad (2)$$

In the Formula (2), T_i represents the traffic accessibility of the city i, and n represents the number of cities in the region.

2.1.2 Measurement of the change in urban scale

Regarding the measurement of the change of urban scale, previous research focus on the change of household registration or permanent resident population (Yang and He, 2018); the relative change of land use (Wu and Li, 2019) and other perspectives, the research perspective is relatively simple. However, the change of urban scale can be reflected by multi-dimensional perspectives of economy, population, land use, employment, *etc*. Considering the availability of current data, this paper constructs a comprehensive indicator system from four parameters: population, economy, employment, and land expansion (Lin et al., 2017), in order to measure the change of the urban scale. The indicator system is shown in Table1:

Table 1 The urban scale indicator system

Target layer	Primary indicator	Secondary indicators
The urban scale indicator system	Population	Total population at the end of the year (10 000 people)
		GDP(10 000 yuan (RMB))
	Economy	GDP per capita (billion yuan)
		Rate of GDP growth (%)
		Government revenue (10 000 yuan)
		Public finance expenditure (10 000 yuan)
	Employment	Number of employees (10 000 people)
		Urban unemployment rate (%)
	Land expansion	Built-up area (km²)
		Population density (people/km²)

In the calculation used in the model, 'range' is used to carry out the dimensionless treatment of each evaluation index. The standard deviation method is then used to evaluate the weight of each index in the measurement system. The change rate of urban scale is then calculated as follows:

$$index_t = \sum_{k=1}^{m} x_{kt} w_k \quad (3)$$

$$\Delta index = index_{2016} - index_{2011} \quad (4)$$

$Index_t$ is a comprehensive value of the urban scale in the year t; x stands for some necessary index of the city, w is the weight of each index; $\Delta index$ is the change rate of the urban scale between 2016 and 2011; $index_{2016}$ and $index_{2011}$ are the comprehensive values of the urban scale in the years 2016 and 2011. It should be noted that the concentration of the population in the region drives the construction of industries, commerce, office services, *etc*., and ultimately promote the expansion of land use. Therefore, population density is an important reflection of land expansion.

2.1.3 Geographically weighted regression (GWR) model measurement

In the past, when exploring the factors affecting the urban scale, it was based on indicators that characterizes urban history, economy, and social development, and the scholars always use the correlation coefficient, SLM, SEM, logistic regression, and VAR to explore the impact of various factors on the urban scale. In comparison with the general regression model, GWR can reveal the spatial differentiation characteristics of the factors for different regions (Guo et al., 2017b; Wang et al., 2017). GWR models introduce the data for geographical position into the regression parameters and use the sub-sample information from the adjacent observations to estimate the local regression. The parameters change according to the change in the spatial position. Furthermore, the ordinary linear regression (OLS) model is extended. The model makes use of the following formula(5):

$$y_i = \beta_0(u_i, v_i) + \sum_k \beta_k(u_i, v_i) x_{ik} + \alpha_i \quad (5)$$

where y is an $n \times 1$ dimensional vector variable, x_{ik} is an $n \times k$ dimensional vector variable, β_k (u_i,v_i) represents the regression coefficient of the variable k at the regression point i, (u_i, v_i) represents the spatial position of i points, and α_i is an $n \times 1$ dimensional vector which adopts a normal distribution.

2.2 Data

The national road traffic network of 2013 (Sinomap Press, 2013), including ordinary railways, highways, national highways, and provincial roads, was used in the study. According to the requirements of the Highway Engineering Technical Standard of the people's Republic of China (JTGB-2014) (Ministry of Transport of the People's Republic of China, 2014), the speed limits on different types of roads are as follows: the speed of expressways is 120 km/h, national highways is 100 km/h, railways is 90km/h, provincial highways is 80 km/h, and county roads and other roads is 40 km/h. In terms of the actual operation of high-speed railway, the speed limit is 300 km/h. Other economic datas were derived from the China Statistical Yearbook in 2011; 2016 (National Bureau of Statistics, 2012; 2017), The study area covered a total of 40 cities in Northeast China. The following should also be noted: 1) The spatial impact generated by high-speed railway presents temporal hysteresis. Most of the high-speed railway branch lines (such as Harbin-Qiqihar; Shenyang-Dandong; Dalian-Dandong) in the Northeast China were essentially called into operation in 2015. The spatial impact on regional development has thus not yet been clearly obversed. Therefore, this study only considered the Harbin-Dalian high-speed railway (opened in December 2012) to explore the spatial impact on the urban scale. 2) In order to reasonably measure the change rate of accessibility influenced by high-speed railway, the following assumptions were made: it was assumed that the highways and the ordinary railways were unchanged during the planning period; moreover, the distance of high-speed railway entrance or railway stations of the city was within 15 km, and each transfer was completed by cities above the county level.

3 Results

3.1 Analysis of the space-time convergence effects of high-speed railway (HSR)

3.1.1 Strengthening the spatial differentiation of traffic development and promoting the formation of HSR economic belt

The change rate of accessibility, is obtained from the

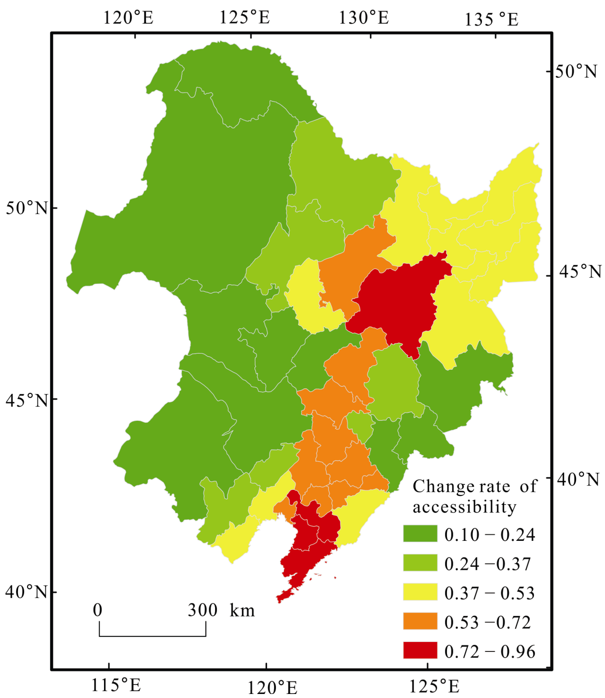

Fig. 2 The distribution of accessibility changes from 2011 to 2016

ratio of the change in the value of accessibility after the opening of HSR to the pre-opening accessibility value. The greater the change rate, the more significant the space-time convergence effects. As shown in Fig. 2, the Harbin-Dalian HSR has made great improvements in the accessibility level for all cities, but at the same time it has further strengthened the spatial polarization characteristics, and the imbalance has increased. Specifically, the increase in accessibility from the HSR has demonstrated attenuation characteristics. After the opening of the HSR, the traffic accessibility for 10 cities along the HSR line increased by more than 60%, which is more significant than other cities in Northeast China. Among them, Dalian and Harbin, which are located at both ends of the HSR, showing the largest increases at 96% and 87%, respectively. However, cities farther away from the HSR were exposed to a lower degree of promotion. Cities such as Hulunbuir in Inner Mongolia, and Yanji in Jilin, the increase was only approximately 15%. This clearly demonstrated the formation of HSR economic belt. Additionally, on a provincial level, the increase in accessibility for Liaoning and Jilin were higher than that for Heilongjiang and Inner Mongolia. The rates of increase for Liaoning, Jilin, Heilongjiang, and Inner Mongolia were 35%, 21%, 13%, and 20%, respectively. The imbalance in traffic development accelerated the factors flow between regions, and constantly affected the relative advantages of each city in the region, which finally led to the change of urban scale.

3.1.2 Changes in commuting mode, inter-provincial and inter-regional cooperation gradually become popular

As shown in Table 2, by analyzing the change rate of accessibility (within the province and inter-provincial), it was found that HSR exerted a greater influence on inter-provincial accessibility than on the accessibility within the province. Overall, the change rate of inter-provincial accessibility was approximately 26%, but

Table 2 Statistics on the change rate of accessibility

Citiy	Within the province	Inter-provincial	Citiy	Within the province	Inter-provincial	Citiy	Within the province	Inter-provincial	Citiy	Within the province	Inter-provincial
Anshan	42.76	84.68	Fushun	28.24	67.20	Jinzhou	14.90	56.12	Songyuan	4.30	27.86
Baicheng	3.54	20.01	Fuxin	5.64	39.43	Liaoyang	34.85	79.15	Suihua	3.42	95.72
Baishan	0.92	20.79	Harbin	1.46	144.94	Liaoyuan	15.36	41.63	Tieling	50.14	66.25
Benxi	20.95	64.98	Hegang	3.30	51.96	Mudanjiang	2.39	67.17	Tonghua	0.25	24.66
Chaoyang	7.25	37.49	Heihe	1.90	41.80	Panjin	23.05	68.76	Tongliao	0.00	11.09
Chifeng	0.00	23.84	Hulunbuir	0.00	14.38	Qitaihe	0.79	49.49	Hinggan League	0.00	17.13
Dalian	87.46	98.97	Huludao	11.94	51.77	Qiqihar	1.37	49.58	Yanji	4.22	21.16
Daqing	2.17	60.94	Jixi	1.40	52.56	Shenyang	40.30	75.51	Yichun	4.01	68.25
Da Hingga Ling Prefecture	1.30	27.24	Jilin	4.84	40.38	Shuangyashan	2.80	51.39	Yingkou	37.46	82.75
Dandong	3.74	49.82	Jiamusi	2.92	56.34	Siping	22.82	72.89	Changchun	7.63	70.87

Note: the change rate of accessibility within the province (inter-provincial) is obtained from the ratio of the change in the value of accessibility that between the city with other cities that in the same (other) province after the opening of HSR to the pre-opening accessibility value the change rate of the accessibility within the province was only 7%. At the same time, the inter-provincial accessibility of all cities in Northeast China has been significantly improved, while the accessibility within the province of some cities surrounding Northeast China is unchanged. In terms of each province, the change rate in the accessibility within the province for Liaoning, Jilin, and Heilongjiang was 18%, 4%, and 3%, respectively, but that of Inner Mongolia was not significant. The change rate in inter-provincial accessibility for Liaoning, Jilin, and Heilongjiang were 38%, 24%, and 16%, respectively, and that of Inner Mongolia was 22%. It can be seen that the HSR can change the commuting mode that was limited within the province or surround the city, inter-provincial and inter-regional commuting models will become more common. The change in commuting mode can affect the distribution of population and industry, which ultimately affects the urban scale.

3.1.3 The gradually apparent trend of the 'siphoning effect' of HSR

In order to better present the impact of HSR on the development of Northeast China, the study first used the economic linkage model to measure the economic linkage intensity (Meng and Lu, 2011) between cities, and then, based on the rank-size law (Guo et al., 2017a), identified the dynamic evolution of economic development. The results showed that the fitting effect between economic linkage intensity and its order was superior, and the correlation coefficient R^2 was above 0.9. It could be stated that the rank-size distribution effectively satisfied *Zipf's* law. Before the opening of the HSR, the economic linkage intensity in Northeast China demonstrated three scale range characteristics (Table 3). The first scale range involved Shenyang, Changchun, Liaoyang, and Tieling. The second scale range involved Dalian, Harbin, Siping, Anshan, Fushun, Benxi, and Yingkou. At this stage, the distribution of the economic linkage intensity was as follows: the economic linkage intensity of cities in the central of Northeast China or along the main traffic lines is higher than that of cities in surrounding areas.

After the opening of the HSR, the rank-size distribution of the economic linkage intensity changed from a three-scale range to a two-scale range, and the regional development pattern was broken. It was noted that since the opening of the HSR, the *Zipf* index has been greater than 1, and has increased compared with the period preceding the opening of the HSR. In addition, the rank-size distribution of the economic linkage intensity demonstrated a Pareto distribution, with the economic linkage intensity predominantly concentrated in the cities with better development foundations. The gap in the economic linkage intensity was further widened, and cities along the HSR have demonstrated a siphoning effect. At the same time, the ratio between Shenyang, with the highest economic linkage intensity, and Da Hingga Ling Prefecture, with lowest economic linkage intensity, increased from 145 to 488, and the gap widened further. At this stage, the siphoning effect of HSR is greater than the diffusion effect, and the spatial polarization phenomenon has appeared in the region's development.

3.2 Spatial distribution of the change rate of urban scale in Northeast China

3.2.1 The overall pattern of change rate in urban scale

Overall, after the opening of the HSR, there were 12 cities experiencing urban expansion, accounting for 40% of the whole Northeast China cities. Four central cities (Dalian, Shenyang, Changchun, and Harbin) have shown remarkable urban expansion. In addition, there has been some expansion in Yingkou, which is positioned along the HSR. Among these, urban expansion in Dalian is most significant with the change rate of 33%. Additionally, Harbin, Changchun, and Shenyang increased by 17%, 20%, and 12%, respectively. A total of 22 cities demonstrated urban shrinkage, accounting for a

Table 3 Rank-size distribution of the economic linkage intensity

Period	Scale range	Regression equation	*Zipf*–|*q*|	R^2
Before the opening of the HSR	First scale range	Ln*P*=3.820–0.054Ln*R*	0.054	0.989
	Second scale range	Ln*P*=4.629–1.395Ln*R*	1.395	0.960
	Third scale range	Ln*P*=5.619–1.71Ln*R*	1.717	0.939
After the opening of the HSR	First scale range	Ln*P*=4.550–1.848Ln*R*	1.848	0.969
	Second scale range	Ln*P*=6.049–2.358Ln*R*	2.358	0.935

Note: q is the *Zipf* index. Scale range and *Zipf* index are two important indicators of *Zipf*'s law.When $q = 1$, $q > 1$, and $q < 1$, the system is at the optimal distribution , Pareto distribution (centralization) and normal distribution (equilibrium) modes in the natural state total of 55% , and thus indicating that the shrinkage phenomenon in Northeast China has become more common in the past five years. Among these cities, the urban scale of Qitaihe, Suihua, Yichun, and Baishan demonstrated greater decline. The scale of the cities located from the HSR to the periphery was relatively stable. Provincially, Liaoning Province has experienced urban expansion with an increase of 7.2%, Jilin Province was relatively stable with an increase of 0.3%, with the Heilongjiang Province demonstrated significant urban shrinkage with change rate of –2.2%.

3.2.2 The pattern of change in urban scale for different parameters

As shown in Fig. 3, in order to better present the change

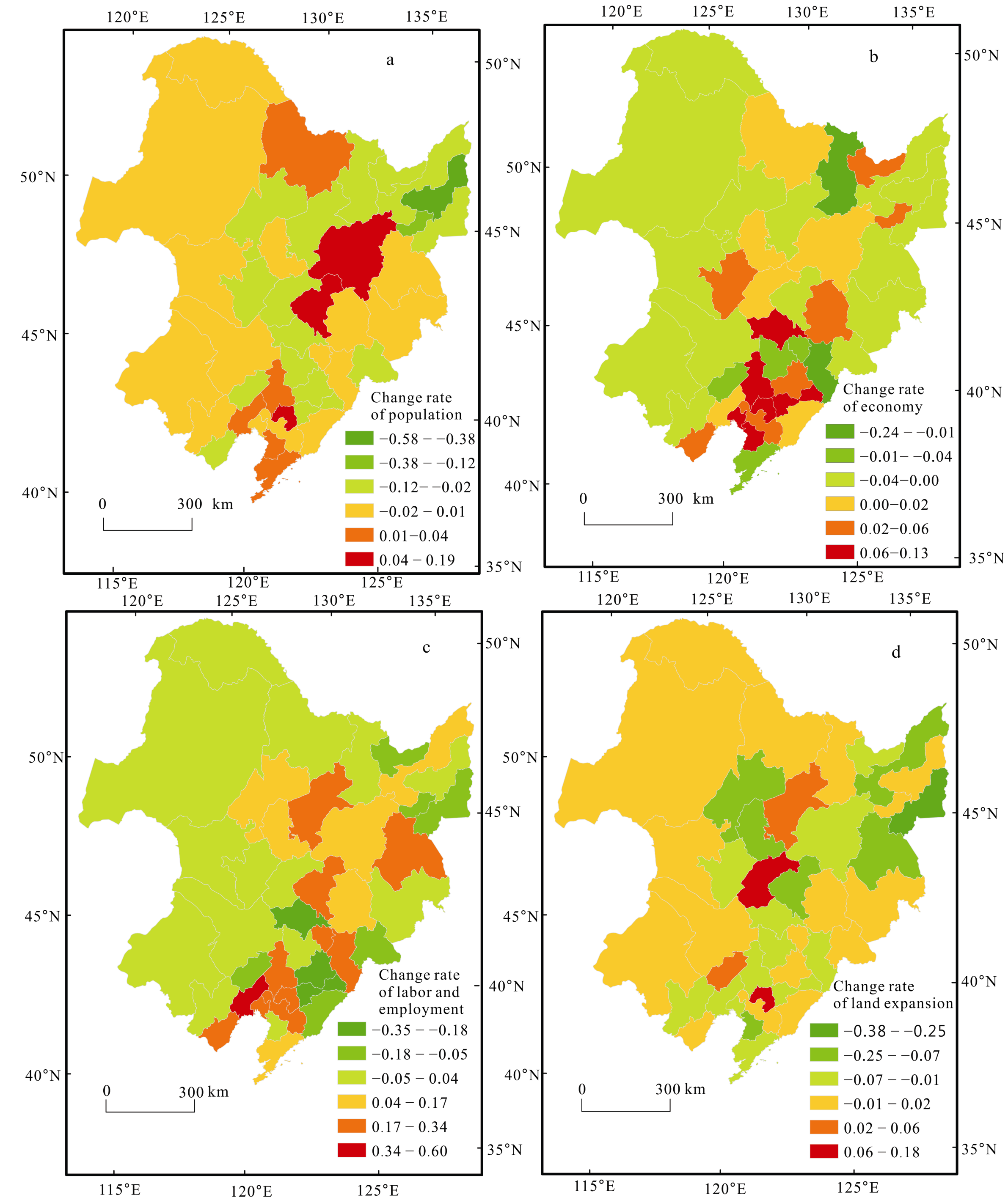

Fig. 3 Spatial distribution of the change rate of the urban scale from different parameters

of urban scale in Northeast China, this study analyzes from four parameters: population, labor and employment, economy, and land expansion.

From the perspective of population change, Northeast China as a whole is subject to population loss. 25 cities experiencing population loss, demonstrating a shrinking trend, accounted for 62.5% of the cities in Northeast China. Among them, Shuangyashan demonstrated the most significant loss, with a negative population growth rate of 58.1%. In contrast, the population of Changchun, Liaoyang, Harbin, and Dalian demonstrated population increases, with population growth rates of 19.5%, 16.4%, 16.3%, and 4.6%, respectively. On the provincial scale, the population loss in Heilongjiang Province was the most noticeable. In terms of spatial distribution patterns, cities with higher population growth rates were densely distributed in central and the southern Liaoning, and cities with higher loss were predominantly concentrated in Heilongjiang Province and the border area between Liaoning and Jilin Province.

In terms of labor and employment, 12 cities experienced deterioration in the labor and employment situation, accounting for 30%. Among them, Siping is the most significant, with a drop of 35.6%, followed by Benxi, Fushun, Jixi, Baishan, and Dandong, with rates of decline of 18.8%, 18.1%, 12.7%, 12.9%, and 11.9%, respectively. In addition, three cities in Liaoning, Jilin, and Heilongjiang provinces demonstrated deterioration of the labor and employment conditions.

In terms of land expansion, the land use in most cities in Northeast China is decreasing. Among them, 26 cities demonstrated land shrinkage, accounting for 30% of the cities in Northeast China. Among them, Jixi demonstrated the most significant land shrinkage, with a shrinkage rate of 38.5%. Songyuan demonstrated the largest land expansion, with an expansion intensity of 18.5%.

In terms of economy, Northeast China has experienced a recession in recent years. 13 cities demonstrated negative growth, including Chaoyang and Tieling in Liaoning and Tonghua in Jilin. The economic recession in Yichun in Heilongjiang was the most significant, with a drop of more than 5%. Dalian, one of the four central cities, also experienced a certain amount of recession, demonstrating a decline of 4%. From the spatial distribution pattern of the change rate in economic scale, the cities with greater economic growth were predominantly concentrated in Liaoning Province. In addition, the increase rate in Yingkou, Benxi, Anshan, Shenyang, and Panjin along the HSR was significantly higher, reaching more than 6%. The increase in Jilin, Heilongjiang, and the eastern Inner Mongolia was relatively limited. The change in the economic development environment is an important reason for the migration from north to south in Northeast China in recent years.

Based on the analysis of each of the parameters, population, economy, labor and employment, as well as land expansion, the change rate in the urban scale along the HSR line and its surroundings was most significant. It can be seen that the space-time convergence effects produced by HSR, and the spatial distribution of the change rate of urban scale, demonstrated significant spatial coupling characteristics. Therefore, the change in transportation mode had a significant spatial impact on the urban scale.

3.3 Analysis of spatial differentiation characteristics of urban scale influenced by HSR

Urban scale is result of historical, economic, social, and transportation factors. Based on the previous research (Deng et al., 2019) and consider the availability of data, the average wages of workers, the per capita road area, the number of college students, the number of doctors, the urban greening rate, industrial sulfur dioxide emissions, industrial waste-water discharge, industrial dust emissions, the total amount of traffic passengers and traffic volume were selected as independent variables. Urban scale index is used as the dependent variable to analyze the impact of various factors on the urban scale. Result finds (Table 4): overall, compared with other factors, the impact of traffic on the urban scale is relatively high; at the same time, compared with the coefficient of traffic before 2011, the coefficient of traffic increased noticeable during 2011–2016, and the impact of the traffic passengers on the urban scale increased from 0.1243 to 0.1639; the impact of the traffic volume on the urban scale increased from 0.1521 to 0.1885. Since the high-speed railway entered a period of rapid development after 2011, it has promoted the passenger and cargo flows across regions to a certain extent, which in turn has increased the impact of traffic on the urban scale. It should be noted that in this section, obtaining the accessibility value of a long sequence is very difficult, replace the accessibility with total amount of traffic passengers and traffic volume.

Table 4 Statistics of regression results

Variable	2000–2011	2012–2016	2000–2016
Average wages of workers	0.2205**	0.2321**	0.2946***
Per capita road area	0.1254*	0.1484**	0.1742**
Number of college students	0.1084	0.1421**	0.1513***
Number of doctors	0.2153**	0.2018	0.1056**
Urban greening rate	0.1256*	0.1102***	0.1725***
Industrial sulfur dioxide emissions	0.1103**	0.1209*	0.1403***
Industrial wastewater discharge	0.1073	0.1201*	0.1304
Industrial dust emissions	0.0075*	0.1475	0.1487*
Total amount of traffic passengers	0.1243**	0.1639**	0.2542***
Total amount of traffic volume	0.1521*	0.1885***	0.2326***
Constant term	0.1087	0.0565**	0.0423
Sample size	12	5	17

Notes: *, **, *** respectively indicate that the statistical levels of 10%, 5%, and 1% are significant, and the values of each variable and each index are replaced by the average of the corresponding indicators of 40 cities in Northeast China

In order to further explore the spatial differentiation characteristics of the impact of high-speed railway on the urban scale in Northeast China, the study selected the indexs of the city which is mentioned above as independent variables, urban scale of each city as dependent variable, to analyze the relationship between them. Through OLS and GWR regression analysis, the AIC and SSE value of the GWR model have a larger decrease than that of the OLS regression model, and the R-squared of GWR model is higher than that of OLS model. Therefore, GWR is more effective. It should be noted that the accessibility can better reflect the development of high-speed railway, in this section, replace the total amount of traffic passengers and traffic volume with accessibility. At the same time, through the geographic variability test, in the semi-logarithmic model, the DIFF of Criterion of traffic accessibility was negative in the year 2011 and 2016 (Table 5), indicating that the influence of traffic on the urban scale presents significant spatial heterogeneity, and local regression analysis should be carried out. The GWR method was then further employed in order to better reveal the spatial differentiation characteristics of the influence of HSR on the urban scale. Results are shown in Table 6.

Overall, the traffic factors showed significant spatial heterogeneity with respect to the urban scale, with the positive effects gradually weakening from north to south in Northeast China. That is, the positive effects of traffic on Liaoning Province were generally higher than those on Jilin and Heilongjiang provinces. Specifically, before the opening of the HSR, there were three kinds of relationships between accessibility and urban scale. There was a negative correlation within most cities in Heilongjiang, and a relatively low correlation within most cities in Jilin Province, a significant positive correlation within most cities in Liaoning Province. After the opening of the HSR, there was only a positive correlation present between accessibility and urban scale, but the correlation coefficient did vary, increasing from the north to the south in Northeast China. These are the most significant reasons for the increase in urban scale in Liaoning Province, while the urban scale in Jilin and Heilongjiang has decreased. This is also an important reason for factors flow from north to south in Northeast China in recent years.

In order to better explain the impact of HSR on urban scale in Northeast China, this study took account of the change in the correlation coefficient between accessibility and urban scale after the opening of the HSR, and then correlated this with the change rate of urban scale in Northeast China. All cities fell into one of the following four groups as noted in Table 6.

Table 5 Variable processing results

Variable	DIFF of criterion		Variable type		Variable	DIFF of criterion		Variable type	
	2011	2016	2011	2016		2011	2016	2011	2016
Average wages of workers	7.95	6.23	Global variable	Global variable	Urban greening rate	–26.75	–25.35	Local variable	Local variable
Per capita road area	–80.82	52.34	Local variable	Local variable	Industrial sulfur Dioxide emissions	–45.13	34.29	Local variable	Global variable
Number of college students	–43.87	–36.82	Local variable	Local variable	Industrial wastewater discharge	–43.86	–53.67	Local variable	Local variable
Number of doctors	9.10	11.75	Global variable	Global variable	Industrial dust emissions	–141.56	–107.23	Local variable	Local variable
Traffic accessibility	–30.75	–22.48	Local variable	Local variable					

Note: DIFF of criterion can reflect whether the variable has spatial variation. When DIFF of criterion >0, it indicates that the variable is a global variable, when DIFF of criterion<0, it indicates that the variable is a local variable

(1) In this group, HSR strengthened the correlation between accessibility and urban scale, and it also exerted a positive influence on urban scale. The correlation between accessibility and urban scale increased after the opening of the HSR for these cities, and lead to improvements in the relative advantage associated with regional development, which exerted a siphoning effect on peripheral or other regional cities, leading to urban expansion. This was predominantly noted in cities such as Shenyang, Dalian, Changchun, Harbin, Yingkou, Jinzhou, and Panjin. For example, in Dalian, the correlation coefficient increased by 0.004 after the opening of the HSR, and the urban scale increased by 33%.

(2) In this group, HSR weakened the correlation between accessibility and urban scale. It also exerted a negative influence on urban scale. Although HSR strengthened the local traffic conditions, it also weakened its correlation with urban scale. These cities were influenced by the siphoning effect exerted by other surrounding cities (cities with better economic foundation). Cities in this group were also located along and around the HSR, such as Fushun, Benxi, Anshan, and Liaoyang.

(3) In this group, HSR strengthened the correlation between accessibility and urban scale, but also exerted a negative influence on urban scale. Compared with other cities, the local traffic conditions were weakened. The opening of the HSR provided convenient conditions for citizens to travel to other cities, which amplified the phenomenon of urban shrinkage. Cities in this group included Jiamusi, Shuangyashan, Qitaihe, and a total of 19 other cities. Such cities were predominantly located on the edge of the Northeast China.

(4) In this group, the effect of the HSR was not significant. The change rate of urban scale in these cities was not significant after the opening of the HSR. Cities in this group included Dandong, Jilin, Tonghua, a total of only three cities.

Table 6 Correlation between traffic accessibility and urban scale

Type	Cities	Correlation coefficient for 2011	Correlation coefficient for 2016	The change of correlation coefficient	Type	Cities	Correlation coefficient for 2011	Correlation coefficient for 2016	The change of correlation coefficient
HSR strengthens correlation and produces negative effects.	Qitaihe	–0.008173	0.000913	0.0075992	HSR strengthens correlation and produces positive effects	Chifeng	0.002860	0.007667	0.0040204
	Yichun	–0.007920	0.000781	0.0072864		Yingkou	0.002904	0.005401	0.0020884
	Baishan	–0.000418	0.002112	0.0021160		Chaoyang	0.002772	0.006809	0.0033856
	Suihua	–0.004950	0.001166	0.0051152		Jinzhou	0.002937	0.006303	0.0028152
	Hegang	–0.006677	0.000946	0.0063664		Shenyang	0.002420	0.004356	0.0016192
	Shuangyashan	–0.009064	0.000748	0.0082064		Harbin	–0.003839	0.001353	0.0043424
	Jiamusi	–0.008503	0.000803	0.0077832		Changchun	–0.000759	0.001848	0.0021712
	Songyuan	–0.001342	0.001639	0.0024932		Dalian	0.003311	0.007315	0.0033488
	Siping	0.000946	0.00209	0.0009568		Hulunbuir	–0.000154	0.001221	0.0011408
	Jixi	–0.007810	0.000979	0.0073508		Panjin	0.002816	0.005335	0.0021068
	Tieling	0.002299	0.002332	0.0000276		Daqing	–0.002860	0.001342	0.0035144
	Qiqihar	–0.002475	0.001287	0.0031464	HSR weakens correlation and produces negative effects	Fushun	0.002563	0.00242	–0.0001196
	Liaoyuan	0.000286	0.002068	0.0014812		Fuxin	0.005082	0.002629	–0.0020516
	Baicheng	0.000462	0.001727	0.0010672		Benxi	0.003190	0.002563	–0.0005244
	Mudanjiang	–0.005951	0.001254	0.0060260		Anshan	0.004246	0.002695	–0.0012972
	Heihe	–0.008877	0.000473	0.0078200		Liaoyang	0.003894	0.002629	–0.0010580
	Da Hingga Ling Prefecture	–0.005544	0.000253	0.0025024		Tongliao	0.003014	0.002211	–0.0006716
	Hinggan League	–0.007788	0.000132	0.0009476		Huludao	0.006941	0.002992	–0.0033028
	Yanji	–0.006644	0.000297	0.0062652		–	–	–	–
The influence of HSR is not significant	Dandong	0.003278	0.003388	0.0000920		–	–	–	–
	Jilin	–0.002134	0.001716	0.0032200		–	–	–	–
	Tonghua	0.000275	0.002211	0.0016192	–	–	–	–	–

4 Discussion

The main academic contributions of this paper can be summed up as follows: firstly, an enrichment of the understanding of the factors affecting the urban scale, taking into consideration transportation factors, to ensure that the research results are appropriate for China in terms of the development of rapid traffic. Secondly, the spatial impact of high-speed railway on the urban scale has significant spatial heterogeneity. Based on the geographical perspective, the spatial differentiation characteristics of the impact of high-speed railway on the urban scale are more targeted to guide regional development. Through empirical analysis, we found that high-speed railway has two sides and make different modes of impact on the urban scale.

4.1 Positive and negative effects of HSR

Northeast China is regarded as a closed area, the operation of Harbin-Dalian HSR, exerted a significant space-time convergence effect on the whole region. The accessibility of each city in the region has been improved, and the communication and cooperation between each city has increased. From this perspective, each city has benefited from HSR. However, the space-time convergence effect of the HSR has demonstrated significant distance attenuation characteristics. The farther away from the HSR, the lower the increase in accessibility. In addition, before the opening of the HSR, the Harbin-Dalian trunk was the most important corridor in the region. Therefore, the opening of the Harbin-Dalian HSR further strengthened the gap between the corridor and the surrounding cities. The imbalance in regional development was increasing, and the spatial polarization characteristics of regional accessibility were particularly significant. An imbalance in regional development is a prerequisite for the flow of elements between cities, and the priority layout of the Harbin-Dalian trunk furthered the imbalance in regional development, which in turn led to a new phase of element flow between cities. The Matthew effect produced by the HSR has caused different cities to face different developmental situations: siphoning and diffusion. At this stage, in terms of the proportion of shrinking cities in the region, the siphoning effect has dominated the pattern of development.

4.2 Different effects of HSR on urban scale

The siphoning and diffusion caused by HSR has an effect on urban shrinkage and expansion. This study found that the mode of impact of HSR on urban scale can be categorized as one of the following (Fig. 4). First, HSR promoted the relative advantage of local urban traffic, enhanced the correlation between accessibility and urban scale, and then exerted a siphoning effect on the surrounding cities, leading to urban expansion. Such cities were predominantly concentrated along the HSR line and also possessed good development foundations. Second, HSR enhanced the relative advantage of local urban traffic but at the same time weakened the correlation between accessibility and urban scale, leading to urban shrinkage. This kind of city was also concentrated along and around the HSR line, but was siphoned by the cities with good development foundations. Third, HSR weakened the local urban traffic conditions, but at the same time strengthened the correlation between accessibility and urban scale. The population was siphoned away by the cities with superior local traffic conditions. These cities were predominantly concentrated on the periphery. Fourth, HSR weakened the local urban traffic

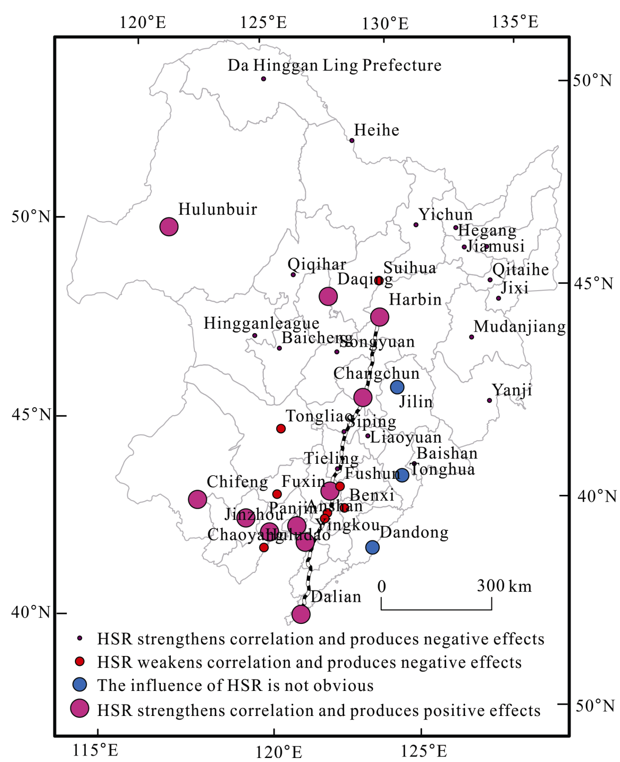

Fig. 4 The impact of HSR on urban scale

conditions along with the correlation between accessibility and urban scale. This situation predominantly occurred during a period of urban diffusion and in the period proceeding completion of the HSR branch line. Further verification is required to confirm this result. There was also a region that was insensitive to traffic development in which the urban scale was relatively stable.

5 Conclusions

The space-time convergence effects produced by the HSR and the spatial distribution of the change rate of urban scale demonstrated significant spatial coupling characteristics, which showed that traffic factor was an important contributor to changes in the urban scale. Based on the accessibility, urban scale measure model, and the GWR model, this paper discussed the spatial impact of the HSR on accessibility, the spatial distribution characteristics of urban scale in Northeast China, and the relationships between them. The conclusions were as follows:

(1) HSR exerted a significant space-time convergence effect, but at the same time it intensified the imbalance in traffic development in Northeast China, and the increase in accessibility demonstrated significant distance attenuation characteristics. In terms of the increase in accessibility of regional traffic, the cities along and around the HSR line benefited most. In terms of the change in accessibility of each province, Liaoning Province benefited the most. At the same time, the HSR has changed the mode of cooperation between the cities in the province. Inter-regional and inter-provincial cooperation models will become especially popular as a result.

(2) In the past 5 years, the urban shrinkage phenomenon in Northeast China has become more common. Overall, the change rate of the urban scale along the HSR line and its surrounding areas has been most significant. It can be seen that the space-time convergence effect produced by HSR and the spatial distribution of the change rate of the urban scale demonstrated significant spatial coupling characteristics. It could be concluded that HSR was one of the important factors responsible for the change of urban scale in the present day.

(3) The impact of the HSR on the urban scale in Northeast China is predominantly divided into four modes which affect cities in different ways, causing them to face the conditions of either expansion or shrinkage.

Based on the above findings, the following countermeasures are proposed. Speed up the construction of other high-speed rail lines or branch lines, improve the layout of fast-traffic lines, and enable more cities to be included in the high-speed railway commuter circle; secondly, for the cities that are easy to be siphoned, we should pay attention to the improvement of the internal quality of the city and meet the residents’ demand for high-quality life, to cope with the negative impact of high-speed railway on the city; for the cities with scale expansion, the urban spatial structure should be rationally optimized to prevent the problem brought about by the disorderly spread.

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