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# High-speed rail new towns and their impacts on urban sustainable development: a spatial analysis based on satellite remote sensing data

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With the rapid expansion of China's high-speed rail network, numerous high-speed rail new towns have been established. While these new towns have brought about significant economic opportunities, they also impose pressure on local resources and environment. Accurately assessing the impacts of high-speed rail new towns on urban sustainable development is therefore a crucial issue to address. Our study employs satellite remote sensing data and spatial econometric methods to evaluate the impacts of 223 high-speed rail new towns in China from 2011 to 2021. The results indicate a gradual narrowing of development disparities among high-speed rail new towns in different cities. The construction of high-speed rail new towns has facilitated the sustainable development of cities. Notably, central high-speed rail new towns demonstrate a more considerably driving effect on the urban sustainable development compared to peripheral ones. The findings of the study provide valuable insights for policymakers and urban planners in China and other countries embarking on high-speed rail development projects. Our research highlights the importance of considering the potential impacts of high-speed rail new towns on the urban sustainable development and the need for careful planning and management to ensure that these newly-established towns contribute to a more sustainable urban future.

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## Introduction

As one of the world's largest developing countries, China has seen significant advancements in economic and urban development in recent years, largely due to the continuous improvement of its transportation infrastructure, particularly in railway network construction (Li et al., 2019). China possesses the longest railway network globally, closely linked to its expansive urban areas and the rapid economic and urban development over the past few decades. As of 2023, China's total railway mileage had exceeded 150,000 kilometers, with high-speed railways surpassing 40,000 kilometers, accounting for more than 70% of the global high-speed rail mileage. Currently, in cities with populations exceeding one million, the coverage rate of high-speed rail surpasses 94%. This extensive network not only fosters economic exchanges between different regions but also plays a crucial role in advancing China's urbanization process (Chen et al., 2024).

With the rapid expansion of China's high-speed rail network, the benefits extend beyond convenient transportation and economic growth. Importantly, it enhances regional accessibility, attracts population concentrations, alters migration patterns, and advances the urbanization process, thereby promoting population mobility and aggregation (Balsa-Barreiro et al., 2019). This has given rise to the new urban development model of high-speed rail new towns. Centered around high-speed rail stations, these new towns have quickly emerged as new focal points for regional development. The concept of high-speed rail new towns has recently attracted significant attention in urban planning (Lin and Xie, 2020). It centers on high-speed rail transport and involves the planning and construction of high-quality, efficient public service facilities, including ecological, cultural, educational, medical, and commercial centers (Kuang et al., 2021), in order to establish a new type of cities supported by high-speed rail, information technology, and eco-friendly technologies (Chang et al., 2022). With the fast and convenient features of high-speed rail, it enables rapid connections with other cities, promoting population mobility and economic exchanges.

Currently, China has planned and constructed over 300 high-speed rail new towns, with more proactive actions in the eastern region (Chang and Zheng, 2022). Cities such as Hangzhou, Suzhou, Liaocheng, Tianjin, Guangzhou, and Shanghai were among the first to announce their high-speed rail new town plans. These cities are located along major high-speed rail routes with high population density. The government work reports have emphasized the optimization and adjustment of urban spatial structures through the development of high-speed rail new towns to promote high-quality urban development (Wang and Gu, 2019).

As shown in Fig. 1, high-speed rail new towns can be classified into two types: central and peripheral. Central high-speed rail new towns are geographically close to the core urban areas, allowing for the full utilization of existing urban resources and infrastructure (Wenner and Thierstein, 2022). However, central high-speed rail new towns face challenges such as excessive land resource exploitation, declining environmental quality, and unequal resource allocation during the development process (Shahraki, 2022). On the other hand, peripheral high-speed rail new towns are located on the outskirts or suburban areas of cities, where land resources are relatively abundant and population density is relatively lower (Streimikiene et al., 2020). The key challenge in constructing peripheral high-speed rail new towns lies in balancing urbanization with land use and farmland protection, avoiding excessive encroachment on agricultural and natural resources while maintaining ecological balance.

Existing literatures on high-speed rail new towns mainly have explored the impacts of their construction on transportation accessibility, analyzes the effects of high-speed rail stations on surrounding housing prices, land use, and industrial structure transformation (Sasaki et al., 1997; Bertolini et al., 2012; Yin et al., 2015). Some scholars have conducted research on the evaluation of the implementation effects of high-speed rail new town plans and their influential factors (Wang et al., 2021; Deng et al., 2020). Additionally, some scholars have also utilized big data technology to study specific high-speed rail new towns (Xu et al., 2018).

High-speed rail new towns have brought uncertainties in the coordinated development of urban economy, resources, and environment systems (Mateus et al., 2008). They are a microcosm of the combined effects of high-speed rail and urbanization strategies. On one hand, the construction of high-speed rail new towns have optimized urban spatial layout, guiding population and economic activities to shift to new urban areas and alleviate resource and environmental pressures in old urban areas (Zheng et al., 2019; Wang et al., 2022). On the other hand, high-speed rail new towns consume significant amounts of land, energy, and water resources, exacerbating the conflict between farmland protection and urban construction. This is not conducive to the development of resource-saving and environmentally friendly cities (Meng et al., 2018). Additionally, recent research indicates that the construction of high-speed rail new towns does not always achieve the anticipated positive outcomes. Particularly in inland areas, the development of these new towns can lead to regional hollowing, reflecting the complex impact of integrating high-speed rail with urbanization strategies (Balsa-Barreiro et al., 2019).

In 2018, the National Development and Reform Commission issued guidelines on the rational development and construction of areas surrounding high-speed rail stations. It pointed out that research on integrating high-speed rail construction and urbanization is still insufficient. Problems such as excessive scale, high functional positioning, and inadequate comprehensive supporting facilities in the development and construction of areas surrounding high-speed rail stations have not been properly addressed. Some high-speed rail new towns lack sufficient attractiveness to populations and industries, and their foundation for sustained and healthy development falls short of the overall planning goals.

Studying the impacts of high-speed rail new towns on urban economic, resource, and environmental systems can provide a scientific basis for planning decisions, promoting regional coordinated development, and ensuring urban sustainability (Sands, 1993). Evaluating the specific impacts of central and peripheral high-speed rail new towns on urban sustainability helps comprehend the variations in their effects. This, in turn, provides decision-makers with a scientific foundation for formulating appropriate development strategies, thereby facilitating efficient, coordinated, and sustainable urban development goals.

However, there is still a lack of relevant research literatures on the impacts of high-speed rail new towns. Most existing studies on high-speed rail new towns treat the opening of high-speed rail as a virtual variable and investigate its impact on regional socio-economic factors, urban spatial evolution, and development patterns around high-speed rail stations. There is a lack of quantitative research directly evaluating the impacts of high-speed rail new towns on the coordinated development of urban economy, resources, and environment.

Presently, China has planned and is in the process of constructing over 300 high-speed rail new towns, a strategic initiative with significant implications for promoting regional economic development and advancing urbanization. However, the construction of high-speed rail new towns is increasingly associated with prominent economic, social, and environmental challenges. Urban sustainable development has long been a focal point within academia, yet the impact of high-speed rail new towns on urban sustainability remains inadequately explored. Our study aims to

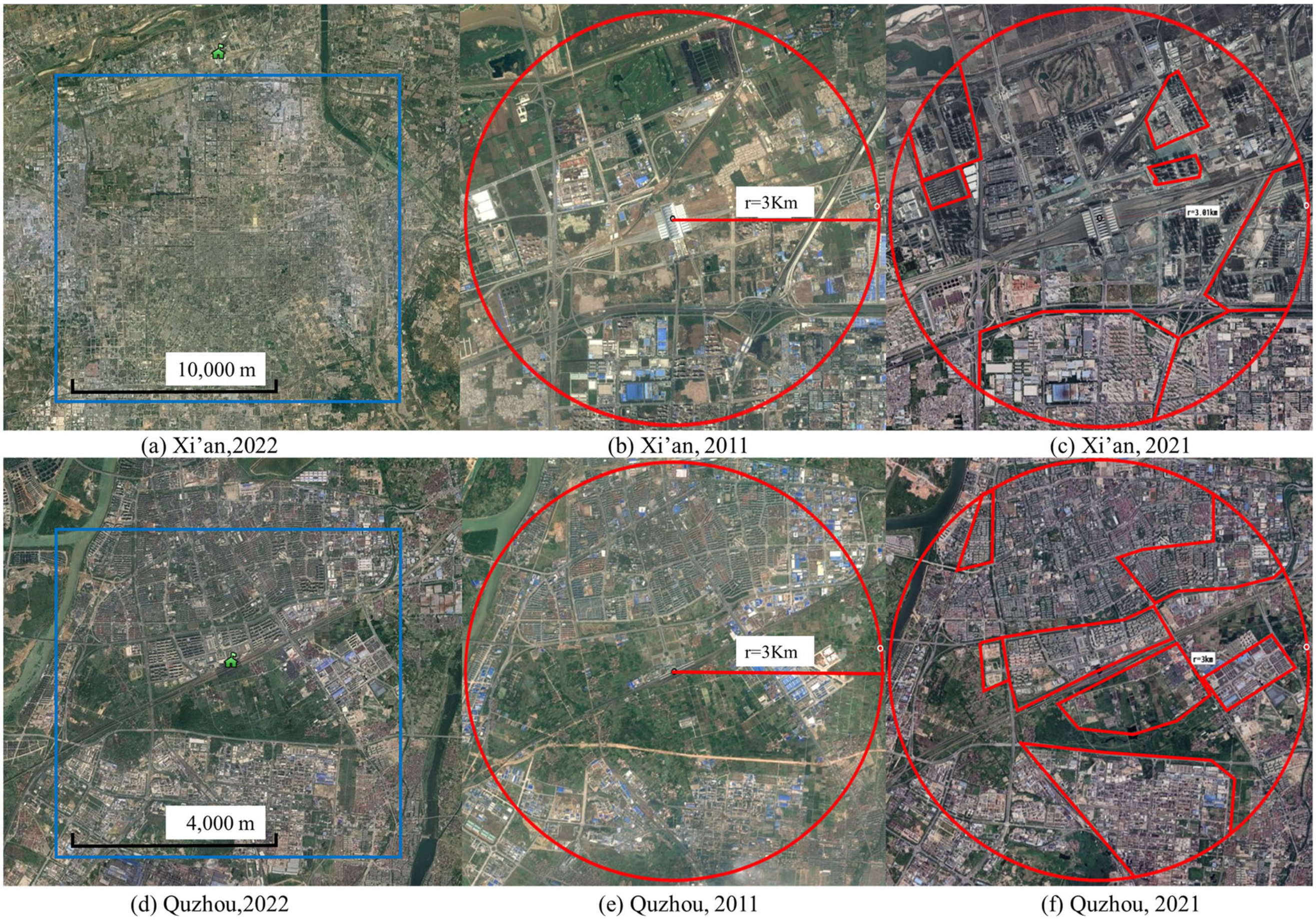


**Fig. 1 Visual demonstration of the spatial differences between the center and periphery of the high-speed rail new city.** The blue box reports the main urban area, the red circular box reports the planned area for the high-speed rail new town, and the red polygon reflects the changes in the built-up area. Figures captured by Keyhole satellites. **a** shows satellite images of Xi'an City, and **b**, **c** shows land use images of Xi'an high-speed rail station in 2011 and 2021. **d**–**f** shows Quzhou City.

assess the impacts of high-speed rail new town construction on urban sustainable development. It seeks to explore construction strategies for different types of high-speed rail new towns, providing feasibility and policy recommendations for the development of high-speed rail new towns in China.

Compared to existing research, this paper is of innovation in three key aspects. Firstly, it assesses urban sustainable development from the perspective of the coordinated development of urban economic, resource, and environmental systems. The study employs spatial econometric models to investigate the impacts of high-speed rail new towns on urban sustainable development, addressing a research gap in this field. Secondly, the study integrates long-term satellite remote sensing observations of nighttime lights and cumulative regional data around high-speed rail stations. It establishes a comprehensive index using the entropy method, creating an evaluation framework that encompasses the development scenarios of multiple urban high-speed rail new towns. Thirdly, the study compares and discusses the specific impacts of central and peripheral high-speed rail new towns on different cities, providing references for the development planning of subsequent high-speed rail new towns.

The remaining sections of this paper are organized as follows: Section 2 introduces the research methods, related models, variable selection, and data sources. Section 3 presents the main research findings. Section 4 discusses the research findings. Section 5 concludes with policy recommendations. The research framework is illustrated in Fig. 2.

## Methods and data sources

**Spatial matrix construction**. In determining the spatial weight matrix, it is important to consider the significant impact of economic interconnections between regions, which is often overlooked by neighbor-based matrices. However, the economic distance matrix also has certain limitations. For instance, when economic distances are equal, it does not necessarily imply the same level of spatial correlation. In reality, regions with higher levels of economic development tend to have a stronger radiating effect on surrounding areas compared to regions with lower levels of economic development (Zhao and Wang, 2022).

Therefore, this study combines a geographical distance matrix with an economic distance matrix to construct a nested matrix, referred to as W1, reflecting the specific impacts of high-speed rail new towns on urban sustainable development. Additionally, a geographical matrix, W2, is constructed to ensure the robustness of the estimation results.

The construction method for the economic-geographic nested matrix W1 is as follows:

$$\begin{aligned} W_{ij} &= \frac{1}{\sqrt{(x_i-x_j)^2+(y_i-y_j)^2}} \times diag(Y_1/Y, Y_2/Y, \cdots Y_n/Y) \\ Y_i &= \frac{1}{t_n-t_0+1}\sum_{t_0}^{t_n} Y \end{aligned} \tag{1}$$

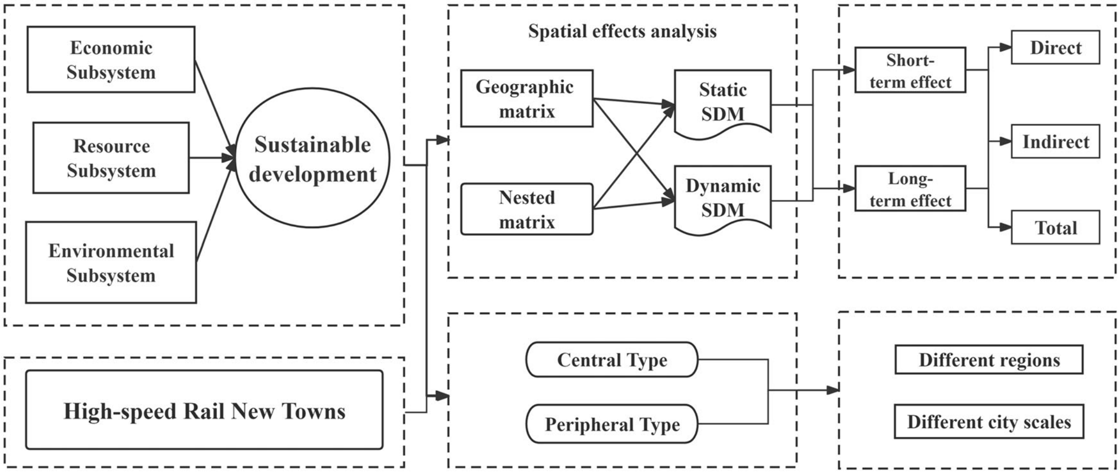


**Fig. 2** Research framework.

The construction method for the geographic distance matrix W2 is as follows:

$$W_{ij} = \frac{1}{\sqrt{(x_i - x_j)^2 + (y_i - y_j)^2}} \tag{2}$$

In this study, the variables $x_i$ and $y_i$ represent the latitude and longitude coordinates of provincial capital cities in various regions, respectively. The data for these coordinates were obtained from the National Basic Geographic Information Center.

The variable $Y_i$ represents the per capita GDP of each city during the observation period, while $Y$ represents the per capita GDP of all cities during the observation period.

**Spatial Durbin model**. We established a dynamic spatial Durbin model with lagged terms to analyze the impact of HSRNT on urban sustainable development. In contrast to the static spatial Durbin model, the dynamic spatial Durbin model not only takes into account dynamic effects and spatial spillover effects but also helps alleviate endogeneity issues (Deng et al., 2022; Chen et al., 2023; Gu et al., 2022). The specific model is as follows:

$$LnUSD_{it} = \alpha + \beta^* W_{ij}{}^*(LnUSD_{it} + LnUSD_{it-1} + LnHSRNT_{it} + LnX_{it}) + \beta_1 LnUSD_{it-1} + \beta_2 LnHSRNT_{it} + \gamma \sum LnX_{it} + \mu_i + \lambda_t + \zeta_{it} \tag{3}$$

Where $USD_{it}$ represents the sustainable development of the city, $USD_{it\text{-}1}$indicates the lag period, $HSRNT_{it}$ reflects the developmental status of the HSRNTs, and $W_{ij}$ signifies the spatial weight matrix. $X_{it}$ comprises control variables, which encompass foreign direct investment ($FDI_{it}$), the ratio of total social retail consumption to GDP ($TRSCG_{it}$), urbanization rate ($URB_{it}$), digital economic development level ($DE_{it}$), and population density ($PD_{it}$). To address potential heteroscedasticity and its impact on estimation results, we have logarithmically transformed the variables.

The LM test indicates that a spatial econometric model is more suitable than a non-spatial econometric model. The Wald_SDM/SAR and LR_SDM/SAR values pass the significance tests at the 1% level, rejecting the null hypothesis that the Spatial Durbin Model can degenerate into a spatial autoregressive model. Similarly, the Wald_SDM/SEM and LR_SDM/SEM values also pass the significance tests at the 1% level, rejecting the hypothesis that the spatial Durbin model can degenerate into a spatial error model. Therefore, this paper employs a spatial Durbin model that accounts for both fixed time and spatial aspects as the empirical model. The results are presented in Table 1.

**Table 1 Spatial Durbin model suitability tests.**

| Inspection type | | W1 | W2 |
|---|---|---|---|
| LM test | Moran's I | 34.967*** | 42.690*** |
| | LM_error | 1209.143*** | 1802.531*** |
| | Robust_LM_error | 184.168*** | 187.933*** |
| | LM_lag | 1139.405*** | 2039.402*** |
| | Robust_LM lag | 114.429*** | 424.804*** |
| LR test | LR_SDM/SAR | 47.30*** | 77.08*** |
| | LR_SDM/SEM | 54.73*** | 83.17*** |
| Wald test | Wald_SDM/SAR | 39.14*** | 78.00*** |
| | Wald_SDM/SEM | 40.94*** | 83.96*** |
| Fixed effects test | LR_both/ind | 575.60*** | 416.98*** |
| | LR_both/time | 5974.81*** | 5060.75** |

***$p$-value < 0.01.

**Fixed effects model**. Once spatial correlation is identified between the high-speed rail development indicators and urban sustainable development, it may be inappropriate to persist in using spatial econometric models to examine the impact of high-speed rail development on urban sustainability in different regions. This is because, in the presence of existing spatial correlation, investigating the impact of high-speed rail development on individual regional areas would disregard the effects of spillovers into other regions, potentially leading to biased estimation results. To address this issue, we employed a fixed effects model while controlling for time and studying individuals. The model is as follows:

$$LnUSD_{it} = \alpha + \beta LnHSRNT_{it} + \gamma \sum LnX_{it} + \mu_i + \lambda_t + \zeta_{it} \tag{4}$$

In the equation above, u represents individual fixed effects, and r denotes time-fixed effects. All other variables are identical to those in Eq. (3).

**Urban sustainable development**. We concur with the viewpoint of Jegatheesan et al. (2009): the coordinated development among subsystems is crucial for achieving sustainable development. Building upon the research of Xing et al. (2019), Ren et al. (2023), Duygan et al. (2022), Allam et al. (2022), Wen et al. (2022), R. Zhao et al. (2022), we have taken into account the influencing factors of urban economic, resource, and

**Table 2 Evaluation indicators for urban sustainable development.**

| Goal Layer | Criteria Layer | Indicator Layer |
|---|---|---|
| Economic system | Economic size | GDP (+) |
| | | City financial revenue (+) |
| | | Total fixed asset investment in society (+) |
| | | End-of-year balance of deposits in financial institutions (+) |
| | Economic structure | Proportion of tertiary industry output (+) |
| | | Proportion of secondary industry output (+) |
| | Economic quality | Per capita GDP (+) |
| | | End-of-year balance of urban and rural residents' savings (+) |
| | | Total retail sales of social consumer goods (+) |
| Resource system | Resource supply | Energy production volume (+) |
| | | Total power generation (+) |
| | | Per capita cultivated land area (+) |
| | | Total water resources (+) |
| | | Forest coverage (+) |
| | Resource consumption | Total energy consumption (-) |
| | | Industrial electricity consumption (+) |
| | | Per capita water consumption (-) |
| | Resource quality | Energy consumption per unit of output value (-) |
| | | Water consumption per unit of output value (-) |
| | | Electricity consumption per unit of industrial output value (-) |
| | | Cumulative sunshine duration per year (+) |
| Environmental system | Environmental pollution | Domestic wastewater discharge (-) |
| | | Industrial exhaust emissions (-) |
| | | Industrial solid waste emissions (-) |
| | | Industrial smoke and dust emissions (-) |
| | | Average annual PM2.5 concentration (-) |
| | | Industrial SO2 emissions (-) |
| | | Total carbon emissions (-) |
| | Environmental governance | Harmless treatment rate of domestic solid waste (+) |
| | | Comprehensive utilization rate of solid waste (+) |
| | Environmental quality | Green coverage rate of built-up areas (+) |
| | | Per capita park green space area (+) |
| | | Carbon sequestration of vegetation (+) |

environmental systems, establishing an evaluation indicator system as illustrated in Table 2.

**High-speed rail new towns**. To accurately assess the development of high-speed rail new cities, we utilized satellite remote sensing observation data and employed the entropy method to integrate nighttime light data and built-up area into a composite index. There are three reasons for using these data: Firstly, there is a lack of comprehensive statistical data on the development of high-speed rail new cities nationwide. Remote sensing data can provide a long time series and relatively objective information on high-speed rail new cities. Secondly, the spatial resolution of nighttime light data is 0.5 km × 0.5 km, while land use data has a higher precision of 30 m × 30 m, enabling us to analyze the development of high-speed rail new cities more accurately. Thirdly, we synthesize both sets of data to use together as the nighttime light data can reflect internal economic activities within high-speed rail new cities, while built-up area can reflect population concentration.

Drawing on the research of Xu and Tan (2020), Shen and Dong (2019), Black and Henderson (1999), Xu et al. (2022), and Luck (2007), the selected control variables include foreign direct investment, total social retail sales, urbanization, digital economy, and population density.

**Data sources**. The carbon emissions and vegetation carbon sequestration data in Table 2 are sourced from the CEADS database, while the PM2.5 concentration data is obtained from the laboratory at Dartmouth College. The remaining data is derived from various official publications and databases, including the "China Urban Statistical Yearbook," "China Urban Construction Statistical Yearbook," EPS database, CSMAR database, and urban statistical bulletins. Control variables and their data sources are drawn from the "China Urban Statistical Yearbook," "China Regional Economic Statistical Yearbook," and "China Statistical Yearbook," spanning the years 2011 to 2021. Samples with severe data gaps have been excluded, and interpolation has been applied to fill in some missing data.

The most commonly used nighttime light remote sensing data currently come from the DMSP-OLS (1992–2013) and NPP-VIIRS (2012-) sensors. However, these two datasets have differences in satellite sensor parameters, spatial resolution, spectral response characteristics, and the "saturation effect" in DMSP/OLS data(Chen et al., 2021). Therefore, these datasets cannot be directly used together. Instead, a long-term, continuous, and comparable nighttime light time series dataset(https://dataverse.harvard.edu/dataset.xhtml?persistentId=doi:10.7910/DVN/YGIVCD#) was employed in this study. This dataset shares the same parameters and data quality as the NPP-VIIRS nighttime light data, with a spatial resolution of approximately 500 meters and units in nanoWcm-2sr-1 (Cui et al., 2023; Shi et al., 2023).

For the extraction of built-up area data, we utilized yearly land cover data for China from 1990 to 2022, at a 30-meter resolution, obtained by Professor Jie Yang and Professor Xin Huang at Wuhan University through the classification of Landsat satellite images (Yang and Huang, 2021). Subsequently, we used the Google Earth Engine (GEE) platform to extract the yearly mean and total nighttime light values and built-up area within a

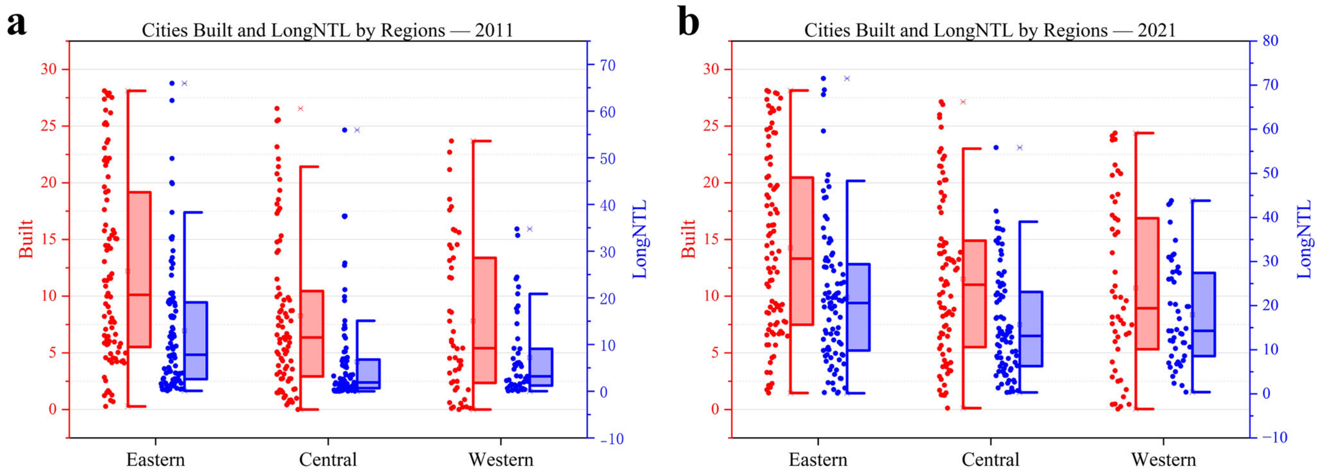


**Fig. 3 The changes in urban built-up areas and nighttime lighting data in the eastern, central, and western regions. a, b** represent 2011 and 2021, respectively.

3-kilometer buffer zone around each high-speed rail new city. A radius of 3 kilometers, covering an area of 28.26 square kilometers, encompasses the core area of high-speed rail new towns. This region is the most vibrant and essential part of the development and urbanization process of new towns.

## Results

**Changes in built-up area and nighttime light data**. The period from 2011 to 2021 witnessed significant growth in the built-up area and nighttime light data. Notably, the growth rate of nighttime light data was considerably higher than that of the built-up area. The development status of built-up areas and nighttime light data exhibited a correlation with geographical locations, with the eastern region outperforming the central region, and the western region showing relatively lower performance (see Fig. 3). However, both the central and western regions demonstrated substantial growth rates. The average growth rates of the built-up area for the eastern, central, and western regions were 39.54%, 86.66%, and 82.75%, respectively, while the corresponding average growth rates for nighttime light data were 148.81%, 356.53%, and 275.91%, respectively.

**Regional characteristics of high-speed rail new towns**. The spatial distribution of high-speed rail new towns exhibits significant spatial disparities, characterized by marked differences in the quantity and density of high-speed rail new town developments on either side of the "Hu Huanyong Line." The development of high-speed rail new towns from 2011 to 2021 is illustrated in Fig. 4a–c. In 2011, well-developed high-speed rail new towns were concentrated in the Beijing-Tianjin-Hebei and Yangtze River Delta regions. By 2021, the development of high-speed rail new towns in various cities had further improved. The development of high-speed rail new towns is not only related to the economic development of the cities but is also influenced by major transportation arteries. high-speed rail new towns along major high-speed rail routes, such as the "Beijing-Shanghai High-Speed Rail," "Beijing-Guangzhou High-Speed Rail," "Beijing-Harbin High-Speed Rail," "Shanghai-Kunming High-Speed Rail," and "Zhengzhou-Xi'an High-Speed Rail," demonstrated more favorable development.

From 2011 to 2016, high-speed rail new towns with high growth rates were concentrated in the central region. However, from 2016 to 2021, the number of high-growth cities significantly decreased, with most cities displaying low or moderate growth rates. Although most cities witnessed growth in their high-speed rail new town development, some cities experienced declines, primarily in the northeastern region. Given that it is challenging for the built-up area to decrease, the primary reason for the decline in the development of high-speed rail new towns in these areas is the weakening of nighttime light. Diminished nighttime light reflects a reduction in economic and human activities in these regions.

**Spatial correlation analysis**. The spatial distribution of high-speed rail new towns and urban sustainable development is not entirely random; it exhibits distinct clustering characteristics, displaying a positive spatial correlation. The global Moran's Index for high-speed rail new town development demonstrates a significant positive trend, initially rising and then declining, while the global Moran's Index for sustainable development index exhibits a slow descent, and both exhibit statistical significance in their *P*-values. The Moran's Index for the high-speed rail city development index shows a notably significant increase in 2013, 2017, and 2021 Fig. 5.

In the Moran Scatter Plot for the high-speed rail city development index, most cities fall within the first and third quadrants, indicating a spatial correlation pattern of "H-H" or "L-L." Furthermore, over time, the clustering effect becomes more pronounced. In the Moran scatter plot for the sustainable development index, most cities also fall within the first and third quadrants, demonstrating an "H-H" or "L-L" spatial correlation pattern. Both the high-speed rail city development index and the sustainable development index exhibit significant spatial correlations among different cities. Failing to account for their spatial relationships when using traditional estimation models can lead to biased results.

**Estimation results and effect decomposition**. Based on the nesting matrix W1 and the geographical distance matrix W2, Table 3 presents the regression results for both the static spatial Durbin model and the dynamic spatial Durbin model. The dependent variable is the logarithm of coupling coordination. The independent variables are the logarithm of the high-speed rail city development index. Fixed effects for time and city entities are also included. In terms of the goodness of fit (R-squared) of the model, both for the nesting matrix W1 and the geographical distance matrix W2, the dynamic spatial Durbin model outperforms the static spatial Durbin model, indicating that the dynamic spatial Durbin model is more robust.

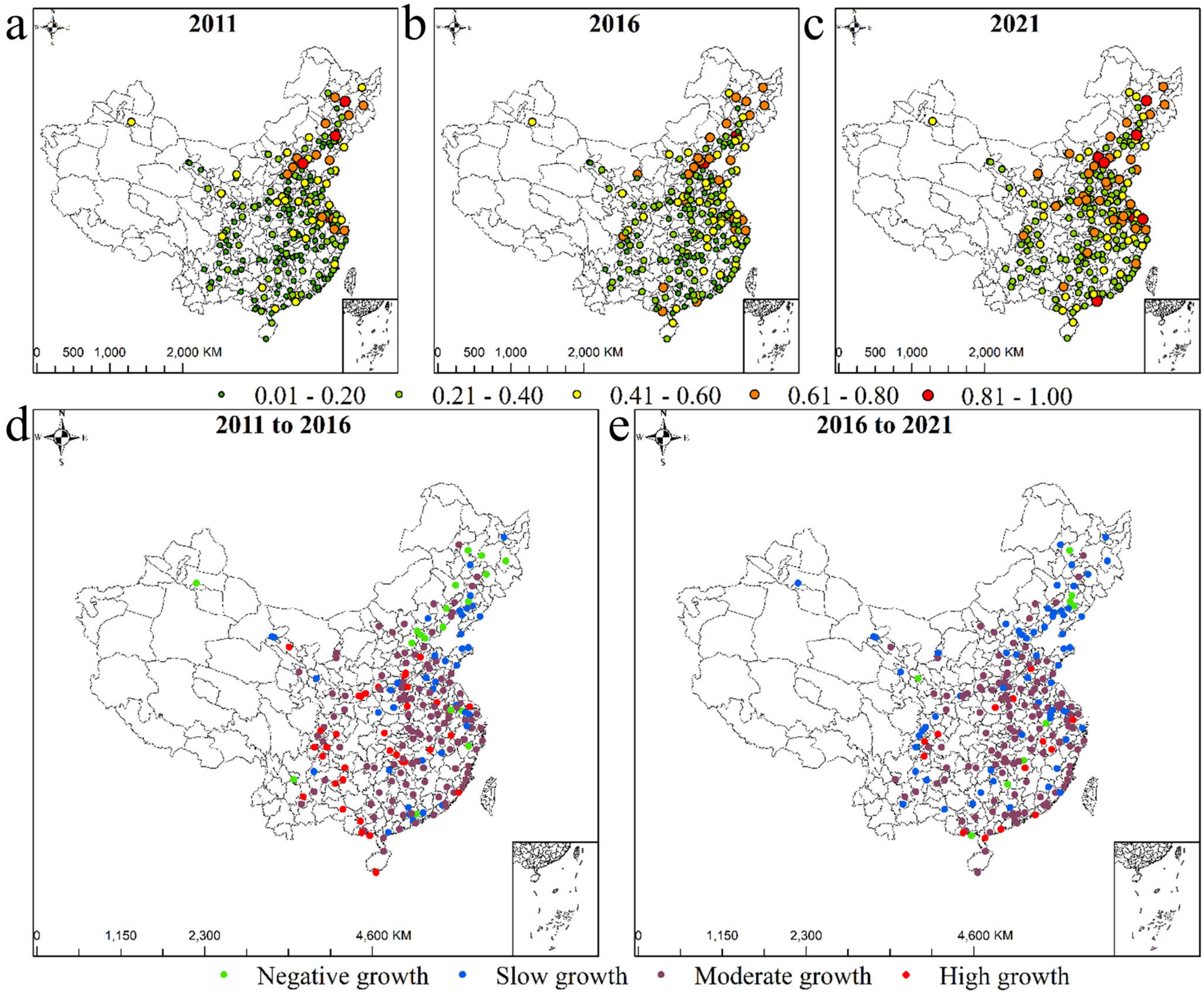


**Fig. 4 Regional characteristics of high-speed rail new towns. a–c** depict the development status of high-speed rail new towns in 2011, 2016, and 2021, respectively. **d**, **e** reflect the changes in the index for each city from 2011 to 2016 and from 2016 to 2021.

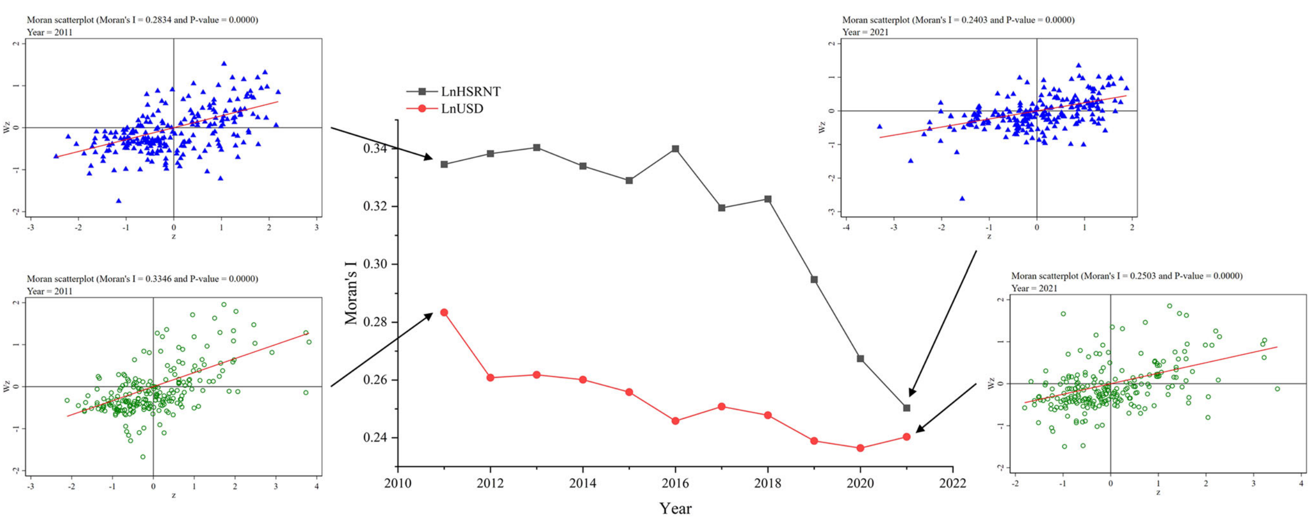


**Fig. 5** Moran's index based on the economic geography nesting matrix (W1).

**Table 3 Regression results for the static and dynamic spatial Durbin models.**

| Variables | W1 | | W2 | |
|---|---|---|---|---|
| | Static SDM | Dynamic SDM | Static SDM | Dynamic SDM |
| $LnUSD_{t-1}$ | | 0.326*** (4.48) | | 0.430*** (5.35) |
| *LnHSRNT* | 0.041*** (5.51) | 0.031*** (3.53) | 0.047*** (6.46) | 0.038*** 4.38 |
| *LnFDI* | 0.016*** (4.32) | 0.016*** (3.71) | 0.015*** (4.13) | 0.016*** 3.74 |
| *LnTRSCG* | 0.009*** (3.72) | 0.011*** (4.24) | 0.009*** (4) | 0.011*** 4.59 |
| *LnURB* | 0.043*** (4.22) | 0.044*** (3.68) | 0.062*** (6.16) | 0.069*** 5.85 |
| *LnDE* | 0.019*** (3.55) | 0.017*** (2.84) | 0.017*** (3.22) | 0.014** 2.35 |
| *LnPD* | 0.053*** (4.22) | 0.053*** (4.04) | −0.006 (−0.57) | −0.014 −1.24 |
| *W*LnHSRNT* | 0.049*** (2.77) | 0.046** (2.20) | 0.060*** (3) | 0.045* 1.92 |
| *W*LnFDI* | 0.026*** (2.98) | 0.032*** (3.10) | 0.029*** (2.62) | 0.014 1.11 |
| *W*LnTRSCG* | −0.038*** (−4.39) | −0.037*** (−3.84) | −0.030*** (−3.88) | −0.025*** −3.15 |
| *W*LnURB* | 0.010 (0.45) | 0.029 (1.17) | −0.136*** (−4.27) | −0.155*** −3.98 |
| *W*LnDE* | 0.027* (1.95) | 0.014 (0.93) | 0.025 (1.5) | 0.015 0.8 |
| *W*LnPD* | −0.064*** (−2.93) | −0.074*** (−3.21) | 0.104*** (3.97) | 0.091*** 3.33 |
| Spatial-rho | 0.219*** | 0.100** | 0.303*** | 0.170*** |
| sigma2_e | 0.001*** | 0.001*** | 0.003*** | 0.004*** |
| Time fixed | Yes | Yes | Yes | Yes |
| City fixed | Yes | Yes | Yes | Yes |
| $R^2$ | 0.673 | 0.795 | 0.621 | 0.818 |

Robust t-statistics in parentheses,***$p < 0.01$, **$p < 0.05$, *$p < 0.1$

**Table 4 Decomposition of the short-term and long-term effects.**

| | Short-term effect | | | Long-term effect | | |
|---|---|---|---|---|---|---|
| | Direct | Indirect | Total | Direct | Indirect | Total |
| *LnHSRNT* | 0.031*** (3.69) | 0.054** (2.36) | 0.085*** (3.53) | 0.035*** (3.97) | 0.099*** (2.75) | 0.133*** (3.43) |
| Time fixed | Yes | Yes | Yes | Yes | Yes | Yes |
| City fixed | Yes | Yes | Yes | Yes | Yes | Yes |
| Control variables | Yes | Yes | Yes | Yes | Yes | Yes |

***$p$-value < 0.01.

The coefficient of the lagged sustainable development ($LnUSD_{t-1}$) is significantly positive at the 1% level, suggesting a clear time-dependent characteristic in regional coupling coordination. The coefficient of the spatial lag term spatial-rho for sustainable development is significantly positive at the 1% level under both spatial weight matrices.

The estimated coefficient for the high-speed rail new town development index is significantly positive at the 1% level, indicating that the development of high-speed rail new towns promotes an increase in urban sustainable development. This coefficient is notably lower than that of the static spatial Durbin model. The coefficient for the spatial lag term ($W*LnHSRNT$) for high-speed rail new towns is significantly positive. This suggests that the development of high-speed rail new towns in a local area positively influences the sustainable development of neighboring cities.

Pace 2009 suggested that when the coefficient of the spatial lag term for the dependent variable is significantly non-zero, using the spatial dubbin model to measure the spillover effects of economic growth can lead to systematic bias. This study is based on the method proposed by Pace to decompose the impact effect of high-speed rail on new towns.

Table 4 presents the results of decomposing the impact of high-speed rail new towns on sustainable development into direct, indirect, and total effects using the partial differentiation method. The regression coefficients for Table 4 based on the economic

**Table 5 Impacts of different types of high-speed rail new towns in various regions.**

| Variables | Eastern cities | | Central cities | | Western cities | |
|---|---|---|---|---|---|---|
| | Peripheral | Central | Peripheral | Central | Peripheral | Central |
| *LnHSRNT* | 0.204** (2.45) | 0.319*** (3.78) | 0.152*** (5.65) | 0.291*** (3.02) | 0.100* (1.96) | 0.126* (1.63) |
| *LnFDI* | 0.085*** (3.29) | 0.134*** (3.23) | 0.015 (0.63) | 0.009 (0.75) | 0.067*** (3.17) | −0.026 (−0.24) |
| *LnTRSCG* | −0.101*** (−4.19) | −0.078*** (−3.61) | 0.036 (0.96) | 0.321*** (2.91) | 0.017 (0.44) | 0.011 (1.7) |
| *LnURB* | 0.130 (1.64) | 0.249*** (2.73) | 0.350*** (3.46) | 0.684** (2.35) | 0.248*** (3.81) | 0.600*** (3.76) |
| *LnDE* | 0.242*** (7.09) | 0.169*** (5.39) | 0.159*** (7.17) | 0.251* (1.82) | 0.204*** (6.66) | 0.149*** (3.08) |
| *LnPD* | 0.067 (1.54) | 0.067*** (2.79) | −0.065 (−0.79) | −0.033 (−0.57) | 0.098 (1.17) | 0.005 (0.11) |
| Constant | −0.788* | −1.562*** | −0.433 | −4.736*** | −1.650*** | −0.146 |
| Time fixed | Yes | Yes | Yes | Yes | Yes | Yes |
| City fixed | Yes | Yes | Yes | Yes | Yes | Yes |
| Obs. | 473 | 517 | 660 | 220 | 352 | 231 |
| $R^2$ | 0.640 | 0.656 | 0.642 | 0.693 | 0.617 | 0.647 |

***$p$-value < 0.01.

geography nesting matrix W1 and the geographical distance W2 exhibit the same sign and level of significance. In terms of short-term effects, the direct effect (0.031), indirect effect (0.054), and total effect (0.085) of high-speed rail new towns on sustainable development are all significant at the 1% level. This implies that the development of high-speed rail new towns in the local area promotes an increase in local sustainable development and simultaneously enhances the sustainable development of neighboring cities, indicating a significant positive spatial spillover effect. Regarding long-term effects, the direct effect (0.035), indirect effect (0.099), and total effect (0.133) of high-speed rail new towns on sustainable development are all significant at the 1% level, demonstrating that high-speed rail new towns also have a positive long-term spillover effect on sustainable development.

**Impacts of different types of high-speed rail new towns on various locations**. Central-type high-speed rail new towns refer to those where the high-speed rail station is located on the edge of a city's traditional central business district (CBD), with the station serving as the core for urban development and construction of the new town area. Peripheral-type high-speed rail new towns, on the other hand, are those where the high-speed rail station is located on the outskirts of the main urban area or in the city's peripheral regions, with development centered around the station. There are significant differences between these two types of new towns in multiple aspects.

Central-type high-speed rail new towns are positioned in the urban core, closely connected to the traditional CBD, and benefit from significant geographical advantages. This type of new town centers around the high-speed rail station and primarily focuses on high-end commercial and office industries. By attracting quality businesses and talent, it may effectively promote the economic prosperity and vitality of the city center. Additionally, the development of central-type high-speed rail new towns are likely to have a profound impact on the urban spatial structure, often forming new urban cores or sub-centers, thereby guiding the overall direction of urban development. Peripheral-type high-speed rail new towns are located at the urban edge or outer areas, with a spatial layout that is relatively independent. These new towns use the high-speed rail station as a cornerstone, aiming to create a new area that integrates comprehensive transportation, residential, commercial, and industrial functions.

Studying the impact of different types of high-speed rail stations is crucial as it helps us better understand the influence of high-speed rail development on urban and regional growth, enabling us to formulate targeted policies and plans. Which type of high-speed rail new town has the most significant effect on urban sustainable development? Which type has the most signicantly promoting effect? These are the questions that we are particularly concerned about.

**Performance of different types of high-speed rail new towns in different regions**. Table 5 reports the estimated results of edge-type and center-type high-speed rail new towns on cities in the eastern, central, and western regions. Overall, regardless of the location of the high-speed rail new city, its impact on urban sustainable development is significantly positive and exhibits significant regional heterogeneity.

Different types of high-speed rail new towns exhibit heterogeneity in elevating urban sustainable development levels, with central types surpassing peripheral ones. The impact coefficients of central and peripheral high-speed rail new towns on the sustainable development of cities in the eastern region are 0.319 and 0.204, respectively, indicating that central types have a greater promotional effect compared to peripheral types. Both central and peripheral high-speed rail new towns significantly contribute to improving the sustainable development of the central and western regions, but the impact of central types is more pronounced than that of peripheral types.

**Performance of different types of high-speed rail new towns in different city types**. The impacts of different types of high-speed rail new towns on different city types is presented in Table 6. Table 6 reports the estimated results for peripheral and central cities concerning small, large, and extra-large cities.

Different types of high-speed rail new towns exhibit heterogeneity in their impact on urban sustainable development, following a hierarchical structure of "extra-large cities > medium-sized cities > small cities > large cities." Across cities of varying population sizes, central-type high-speed rail new towns demonstrate a stronger promotion of urban sustainable development compared to peripheral-type high-speed rail new towns.

**Considering the impacts of high-speed rail new towns on urban population dynamics**. Using 2011 as a baseline, this paper further investigates the impact of high-speed rail new towns on the development of urban ERE systems under scenarios of urban population dynamics. Population dynamics include two aspects: changes in urban population due to migration, and changes due to natural population turnover. The results are presented in Fig. 6.

Figure 6a shows the spatial distribution of the average annual permanent population in cities from 2011 to 2021. It reveals significant differences in population distribution across cities,

**Table 6 Impacts of different types of high-speed rail new towns on different city types.**

| Variables | Small | | Medium-size | | Large | | Extra-large | |
|---|---|---|---|---|---|---|---|---|
| | Peripheral | Central | Peripheral | Central | Peripheral | Central | Peripheral | Central |
| *LnHSRNT* | 0.143** (2.8) | 0.276*** (3.87) | 0.172*** (3.91) | 0.308*** (3.67) | 0.081* (1.72) | 0.216*** (3.59) | 0.278** (2.61) | 0.903 (2.28) |
| *LnFDI* | 0.057 (1.16) | −0.080 (−0.97) | 0.020 (1.22) | 0.031 (0.72) | 0.016 (0.2) | 0.020 (1.20) | 0.011 (0.4) | 0.089 (0.58) |
| *LnTRSCG* | 0.035 (0.71) | 0.006(0.77) | −0.029 (−0.69) | −0.022 (−0.80) | −0.041* (−2.03) | −0.090*** (−2.8) | 0.057 (0.42) | −0.154 (−1.42) |
| *LnURB* | 0.273** (2.73) | 0.792*** (3.78) | 0.215*** (3.38) | 0.526*** (3.96) | 0.154 (1.65) | 0.147 (1.63) | 0.524** (2.18) | −0.039 (−0.32) |
| *LnDE* | 0.148*** (4.13) | 0.061 (0.79) | 0.192*** (8.24) | 0.115*** (2.93) | 0.280*** (7.41) | 0.246*** (10.93) | 0.142*** (4.48) | 0.136* (3.53) |
| *LnPD* | −0.200 (−1.64) | 0.011 (0.13) | −0.122** (−2.26) | 0.044 (0.58) | 0.083(1.34) | 0.048 (1.20) | 0.180*** (4.63) | 0.035 (1.16) |
| Constant | −0.157 | 0.488 | 0.418 | −0.603 | −0.618 | −0.062 | −2.047* | −0.301 |
| Time fixed | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| City fixed | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| Obs. | 253 | 165 | 572 | 440 | 473 | 330 | 187 | 33 |
| $R^2$ | 0.598 | 0.677 | 0.635 | 0.593 | 0.651 | 0.690 | 0.636 | 0.724 |

***$p$-value < 0.01.

divided by the Hu Line. Cities with populations exceeding 10 million, such as Beijing, Shanghai, Guangzhou, Shenzhen, and Chongqing, are concentrated in this area, while cities with populations between 5 and 10 million are mostly found in the eastern and central regions. In contrast, cities in the western region have significantly fewer people compared to the east and central regions. Figure 6b displays changes in population during the study period. Coastal cities and those within a 300 km range of the coast are the main areas of net population inflow, while the northeast and western regions are the main areas of net outflow. Beyond coastal cities, other inland cities like Chongqing, Chengdu, Xi'an, and Zhengzhou have exhibited a significant siphoning effect on the population of neighboring cities. This finding indicates that in recent years, large inland cities have also become strong attractors of surrounding populations, with migrations not just limited to movements from inland to coastal areas.

Figure 6c, d utilize econometric models to examine the impact of high-speed rail new towns on the development of urban ERE systems. Figure 6c explores the effects of high-speed rail new towns on the coordination of urban ERE systems under different scales of population flow. The study finds that compared to cities with net population outflow, the development of high-speed rail new towns significantly enhances the ERE development index in cities experiencing net population inflow. Figure 6d further compares the roles of central and peripheral high-speed rail new towns in scenarios of large-scale population influx. The results suggest that constructing central-type high-speed rail new towns is more beneficial to the coupling and coordination development of urban ERE systems than peripheral-type ones.

## Discussion

The high-speed rail has greatly improved connectivity between different cities, significantly reducing travel distances and enhancing the synergy of regional economic development. Extensive research has been conducted by scholars on various aspects of high-speed rail, including green development (Qin et al., 2023), economic growth (Lawrence et al., 2019; Guo and Ke, 2020), and regional sustainability (Zhang et al., 2020; Vickerman, 2015). However, limited research has focused on high-speed rail new towns. (Dong et al., 2021) utilized multiple research methods to analyze the impact of high-speed rail new towns on regional economies and refuted the claim that they are "ghost cities." Chang et al. (2022) found a significant spatial mismatch in land leasing resulting from developing high-speed rail new towns. This study, on the other hand, focuses on the impact of high-speed rail new towns on urban sustainable development. To the best of our knowledge, this is the first research literature examining the influence of high-speed rail new towns on urban sustainable development.

This study examines the impacts of high-speed rail new towns on urban sustainable development in China. The findings of the study indicate that high-speed rail new towns can have a positive impact on urban sustainable development, but the magnitude of the impact varies depending on the type of city and the location of the high-speed rail station.

The findings of this study underscore the positive contributions of HSR new towns to urban sustainable development. The establishment of HSR new towns has led to enhanced economic vitality, industrial upgrading, resource optimization, and environmental improvements, particularly in regions with robust industrial foundations, abundant human resources, and supportive policy environments. The central region, despite experiencing rapid development, has demonstrated potential for further economic restructuring, investment attraction, and talent mobility under the impetus of HSR new towns.

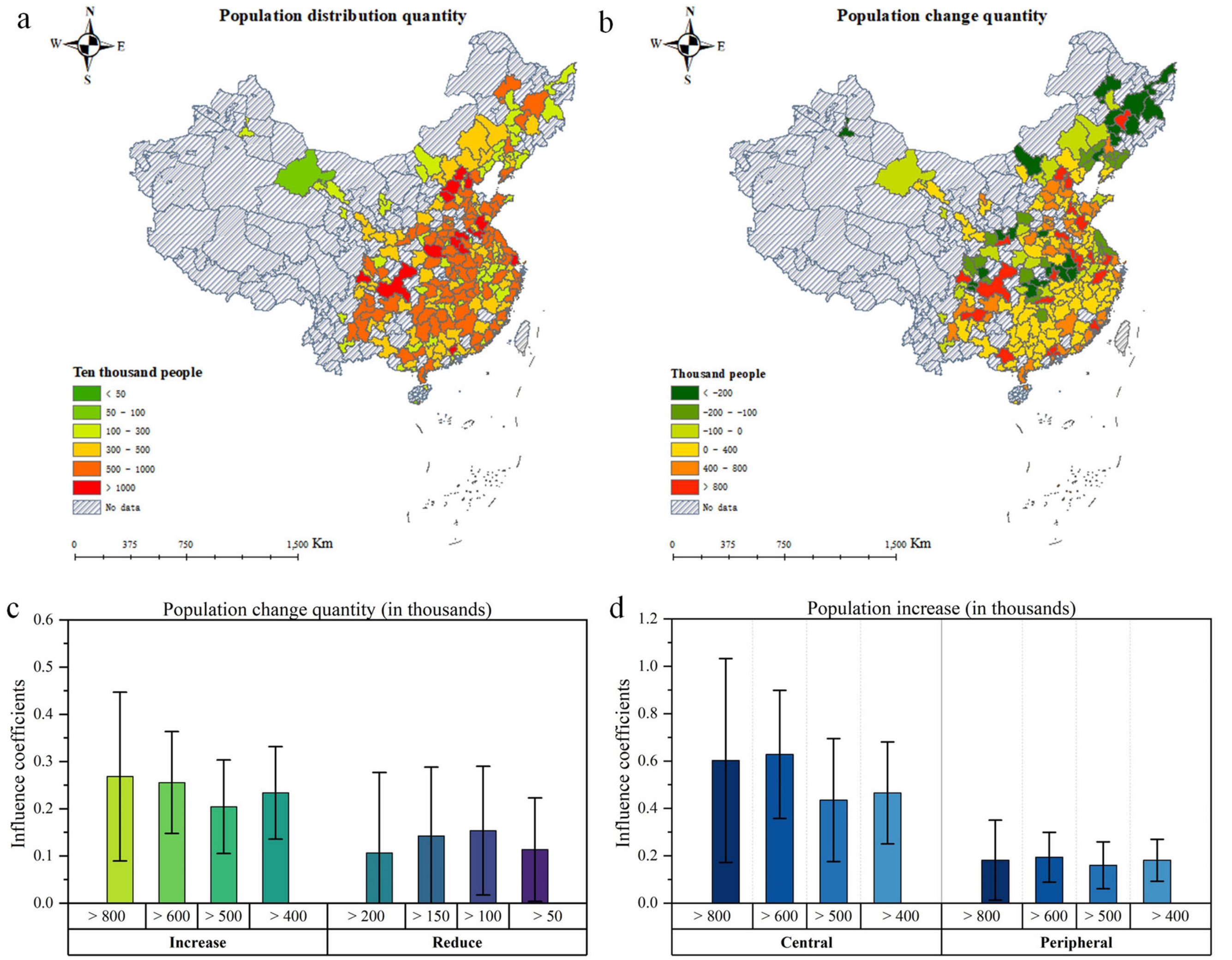


**Fig. 6 Impacts of high-speed rail new towns considering population dynamics. a** shows the spatial distribution of the average annual permanent population in cities from 2011 to 2021. **b** displays changes in population during the study period. **c** shows the estimated results under different population mobility scales. **d** shows the role of different types of new towns in population inflow scenarios.

The construction of high-speed rail (HSR) new towns generates substantial spatial spillover effects on urban sustainable development. For local cities within the region, the short-term and long-term impacts of HSR new towns are generally consistent. However, for neighboring cities, the long-term effects of HSR new towns are significantly greater than the short-term effects. This phenomenon can be attributed to the fact that HSR new towns attract population and resources from surrounding cities, thereby accelerating their rapid development and economic growth. Neighboring cities may experience resource outflows and population reduction in the short term, resulting in relatively smaller short-term effects. Nevertheless, in the long-term development, HSR new towns can drive the development of neighboring cities.

Moreover, our study finds that the impact of high-speed rail new towns on urban sustainable development also exhibits distinct regional disparities. The construction of high-speed rail new towns in the eastern region has the most significant influence on urban sustainable development, as the region possesses a relatively complete industrial foundation, abundant human resources, a higher level of economic development, and policy support. Although the central region has experienced rapid development and has certain potential, its overall strength is relatively weak, the construction of high-speed rail new towns can drive economic structural adjustment, attract investment, and facilitate talent mobility. The western region has a relatively backward infrastructure, industrial development, and resource endowment, so the impact of high-speed rail new towns on its development is relatively small. However, it can still bring about a certain degree of economic growth and optimize resource utilization.

Furthermore, the study highlights the importance of considering the location of HSR stations when evaluating the impacts of HSR new towns. Central-type HSR stations, situated in the heart of urban areas, exert a stronger influence on urban sustainable development compared to peripheral-type HSR stations. This is attributed to their superior transportation accessibility, higher concentration of economic activities, and stronger interconnections among various urban subsystems.

The findings of this study have significant implications for urban planning and policymaking. To harness the full potential of HSR new towns and promote urban sustainable development, policymakers should prioritize balanced development strategies that foster harmonious growth across different city types. Additionally, encouraging cooperation and linkage between HSR new towns and neighboring cities can maximize the diffusion of development benefits and foster regional integration.

In conclusion, this study provides a comprehensive analysis of the impacts of HSR new towns on urban sustainable development, offering valuable guidance for urban planners and policymakers. By promoting balanced development, encouraging cooperation, and protecting the environment, cities can leverage HSR new towns as catalysts for sustainable and inclusive urban growth.

## Conclusion and policy recommendations

**Conclusion**. We collected nighttime light and built-up area's spatiotemporal data for 223 prefecture-level cities in China's high-speed rail new towns from 2011 to 2021 using satellite remote sensing technology. Utilizing a spatial econometric model, the impact mechanisms of high-speed rail new towns on urban sustainable development were investigated. The study analyzed the impacts of high-speed rail new towns on different regions and cities with varying population sizes. Furthermore, the effects of different types of high-speed rail new towns on sustainable development were evaluated. The principal findings are as follows:

First, the built-up area and nighttime lights exhibited significant growth from 2011 to 2021. The growth rate of nighttime lights was notably higher than that of the built-up area. The development status of the built-up area and nighttime lights was correlated with geographic location, with the eastern region outperforming the central region and the western region lagging. The developmental disparities among high-speed rail new towns in different cities have gradually diminished.

Second, high-speed rail new town construction had significantly positive spatial spillover effects on sustainable development, regardless of whether it was under an economic-geographic nested matrix or a geographical distance matrix. Specifically, the impact of high-speed rail new towns on local cities exhibited consistent long-term and short-term effects, while the impact on neighboring cities showed a long-term effect greater than the short-term effect.

Third, high-speed rail new towns could significantly promote urban sustainable development, with the strongest promotional effect in economically developed areas and the weakest in the western region. Different types of high-speed rail stations also exhibited varying impacts on the three main regions, with the strongest influence on the eastern region and the weakest on the western region. The construction effectiveness of "central-type" high-speed rail new towns surpassed that of "peripheral-type" high-speed rail new towns.

**Policy recommendations**. Based on the conclusions drawn from this study, we propose the following policy recommendations:

Prioritize balanced regional development by strengthening intercity transportation connectivity. Despite the diminishing disparities in the development of high-speed rail new towns, it is still necessary to enhance intercity transportation connectivity to promote economic cooperation and exchanges between cities. While the government continues to expand the coverage of the high-speed rail network, improve the convenience and efficiency of high-speed rail transportation, and further facilitate intercity connectivity, considering the relatively inferior development status of the central and western regions, it should increase infrastructure investment, optimize industrial layout, and provide tax incentives to support their development.

Foster intercity cooperation and coordination through enhancing the planning and construction of high-speed rail new towns. The government should continue to invest in developing high-speed rail new towns to facilitate the flow of personnel and goods. Strengthen communication and cooperation mechanisms between cities, promote resource sharing, and implement cooperative projects. At the same time, strengthen policy coordination and institutional integration between regions to provide a better institutional environment and policy support for the development of high-speed rail new towns.

Develop tailored planning and construction policies for different types of high-speed rail stations. Considering the differential impacts of different types of high-speed rail stations on the three major regions, the government should formulate planning and construction policies accordingly. For the eastern region, priority can be given to the development of central-type high-speed rail new towns and major hub stations to further enhance the agglomeration capacity and competitiveness of cities. For the western region, the government should strengthen the construction of peripheral-type high-speed rail stations.

## Data availability

The datasets analysed during the current study are available in the Dataverse repository: https://doi.org/10.7910/DVN/RUTQDI.

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## References

Allam Z, Sharifi A, Bibri SE et al. (2022) The metaverse as a virtual form of smart cities: opportunities and challenges for environmental, economic, and social sustainability in urban futures. Smart Cities 5:771–801. https://doi.org/10.3390/smartcities5030040

Balsa-Barreiro J, Ambuühl L, Menendez M, Pentland A (2019) Mapping time-varying accessibility and territorial cohesion with time-distorted maps. IEEE Access 7:41702–41714

Balsa-Barreiro J, Li Y, Morales A, Pentland A (2019) Globalization and the shifting centers of gravity of world's human dynamics:Implications for sustainability. J Clean Prod 239:117923. https://doi.org/10.1016/j.jclepro.2019.117923

Bertolini L, Curtis C, Renne J (2012) Station area projects in europe and beyond: towards transit oriented development? Built Environ 38:31–50. https://doi.org/10.2148/benv.38.1.31

Black D, Henderson V (1999) A theory of urban growth. J Political Econ 107:252–284. https://doi.org/10.1086/250060

Chang Z, Zheng L (2022) High-speed rail and the spatial pattern of new firm births: evidence from China. Transp Res Part A Policy Pract 155:373–386. https://doi.org/10.1016/j.tra.2021.11.020

Chang Z, Zheng L, Yang T, Long F (2022) High-speed rail, new town development, and the spatial mismatch of land leases in China. Land Use Policy 115:106014. https://doi.org/10.1016/j.landusepol.2022.106014

Chen F, Shao M, Dai J, Chen W (2024) Can the opening of high-speed rail reduce environmental pollution? An empirical research based on difference-in-differences model. Clean Techn Environ Policy. https://doi.org/10.1007/s10098-023-02719-5

Chen H, Yi J, Chen A et al. (2023) Green technology innovation and $CO_2$ emission in China: evidence from a spatial-temporal analysis and a nonlinear spatial durbin model. Energy Policy 172:113338. https://doi.org/10.1016/j.enpol.2022.113338

Chen Z, Yu B, Yang C et al. (2021) An extended time series (2000–2018) of global NPP-VIIRS-like nighttime light data from a cross-sensor calibration. Earth Syst Sci Data 13:889–906. https://doi.org/10.5194/essd-13-889-2021

Cui Y, Zha H, Jiang L et al. (2023) Luojia 1–01 Data Outperform Suomi-NPP VIIRS Data in Estimating $CO_2$ Emissions in the Service, Industrial, and Urban Residential Sectors. IEEE Geosci Remote Sens Lett 20:1–5. https://doi.org/10.1109/LGRS.2023.3244931

Deng T, Gan C, Perl A, Wang D (2020) What caused differential impacts on high-speed railway station area development? Evidence from global nighttime light data. Cities 97:102568. https://doi.org/10.1016/j.cities.2019.102568

Deng Y, You D, Wang J (2022) Research on the nonlinear mechanism underlying the effect of tax competition on green technology innovation - An analysis based on the dynamic spatial Durbin model and the threshold panel model. Resour Policy 76:102545. https://doi.org/10.1016/j.resourpol.2021.102545

Dong L, Du R, Kahn M et al. (2021) Ghost cities" versus boom towns: Do China's high-speed rail new towns thrive? Reg Sci Urban Econ 89:103682. https://doi.org/10.1016/j.regsciurbeco.2021.103682

Duygan M, Fischer M, Pärli R, Ingold K (2022) Where do Smart Cities grow? The spatial and socio-economic configurations of smart city development. Sustain Cities Soc 77:103578. https://doi.org/10.1016/j.scs.2021.103578

Gu B, Liu J, Ji Q (2022) The effect of social sphere digitalization on green total factor productivity in China: evidence from a dynamic spatial Durbin model. J Environ Manag 320:115946. https://doi.org/10.1016/j.jenvman.2022.115946

Guo B, Ke J (2020) The impacts of high-speed rail on sustainable economic development: evidence from the Central Part of China. Sustainability 12:2410. https://doi.org/10.3390/su12062410
Jegatheesan V, Liow JL, Shu L et al. (2009) The need for global coordination in sustainable development. J Clean Prod 17:637–643
Kuang C, Liu Z, Zhu W (2021) Need for speed: High-speed rail and firm performance. J Corp Financ 66:101830. https://doi.org/10.1016/j.jcorpfin.2020.101830
Lawrence M, Bullock R, Liu Z (2019) China's High-Speed Rail Development. World Bank, Washington, DC
Li Y, Xiong W, Wang X (2019) Does polycentric and compact development alleviate urban traffic congestion? A case study of 98 Chinese cities. Cities 88:100–111
Lin J-J, Xie Z-X (2020) The associations of newly launched high-speed rail stations with industrial gentrification. J Transp Geogr 83:102662. https://doi.org/10.1016/j.jtrangeo.2020.102662
Luck G (2007) A review of the relationships between human population density and biodiversity. Biol Rev 82:607–645. https://doi.org/10.1111/j.1469-185X.2007.00028.x
Mateus R, Ferreira JA, Carreira J (2008) Multicriteria decision analysis (MCDA): Central Porto high-speed railway station. Eur J Operat Res 187:1–18. https://doi.org/10.1016/j.ejor.2007.04.006
Meng X, Lin S, Zhu X (2018) The resource redistribution effect of high-speed rail stations on the economic growth of neighbouring regions: evidence from China. Transp Policy 68:178–191. https://doi.org/10.1016/j.tranpol.2018.05.006
Qin C, Yang C, Zhang M, Zhu B (2023) Does high-speed rail improve green development? Evidence from a quasi-natural experiment. J. Clean Prod 407:137174. https://doi.org/10.1016/j.jclepro.2023.137174
Ren X, Zeng G, Gozgor G (2023) How does digital finance affect industrial structure upgrading? Evidence from Chinese prefecture-level cities. J Environ Manag 330:117125. https://doi.org/10.1016/j.jenvman.2022.117125
Sands BD (1993) The development effects of high-speed rail stations and implications for California. Built Environ (1978):257–284
Sasaki K, Ohashi T, Ando A (1997) High-speed rail transit impact on regional systems: does the Shinkansen contribute to dispersion? Ann Reg Sci 31:77–98. https://doi.org/10.1007/s001680050040
Shahraki AA (2022) Renovation programs in old and inefficient neighborhoods of cities with case studies. City Territory Arch 9:28. https://doi.org/10.1186/s40410-022-00174-1
Shen S, Dong X (2019) An empirical analysis of the total retail sales of consumer goods by using time series model. JMF 09:175–181. https://doi.org/10.4236/jmf.2019.92009
Shi K, Ma J, Chen Z et al. (2023) Nighttime light remote sensing in characterizing urban spatial structure. TIG 1:100043. https://doi.org/10.59717/j.xinn-geo.2023.100043
Streimikiene D, Svagzdiene B, Jasinskas E, Simanavicius A (2020) Sustainable tourism development and competitiveness: the systematic literature review. Sustain Dev 29:. https://doi.org/10.1002/sd.2133
Vickerman R (2015) High-speed rail and regional development: the case of intermediate stations. J Transp Geogr 42:157–165. https://doi.org/10.1016/j.jtrangeo.2014.06.008
Wang B, de Jong M, van Bueren E et al. (2022) Planning and developing a high-speed railway new town under state entrepreneurialism in China. Urban Geogr 0:1–22. https://doi.org/10.1080/02723638.2022.2148501
Wang L, Gu H (2019) Studies on China's High-Speed Rail New Town Planning and Development. Springer, Singapore
Wang X, Liu J, Zhang W (2021) How does the spatial structure of high-speed rail station areas evolve? A Case Study of Zhengzhou East Railway Station, China. Appl Sci 11:11132. https://doi.org/10.3390/app112311132
Wen C, Dong W, Zhang Q et al. (2022) A system dynamics model to simulate the water-energy-food nexus of resource-based regions: a case study in Daqing City, China. Sci Total Environ 806:150497. https://doi.org/10.1016/j.scitotenv.2021.150497
Wenner F, Thierstein A (2022) High speed rail as urban generator? An analysis of land use change around European stations. Eur Plan Stud 30:227–250. https://doi.org/10.1080/09654313.2021.1946485
Xing L, Xue M, Hu M (2019) Dynamic simulation and assessment of the coupling coordination degree of the economy–resource–environment system: case of Wuhan City in China. J Environ Manag 230:474–487. https://doi.org/10.1016/j.jenvman.2018.09.065
Xu L, Tan J (2020) Financial development, industrial structure and natural resource utilization efficiency in China. Resour Policy 66:101642. https://doi.org/10.1016/j.resourpol.2020.101642
Xu Q, Zhang P, Liu W et al (2018) A Platform for Fault Diagnosis of High-Speed Train based on Big Data**Project supported by the National Natural Science Foundation, China(61490704, 61440015) and the National High-Tech. R&D Program, China (No. 2015AA043802). IFAC-PapersOnLine. 51:309–314. https://doi.org/10.1016/j.ifacol.2018.09.318
Xu S, Yang C, Huang Z, Failler P (2022) Interaction between digital economy and environmental pollution: new evidence from a spatial perspective. Int J Environ Res Public Health 19. https://doi.org/10.3390/ijerph19095074
Yang J, Huang X (2021) The 30 m annual land cover dataset and its dynamics in China from 1990 to 2019. Earth Syst Sci Data 13:3907–3925. https://doi.org/10.5194/essd-13-3907-2021
Yin M, Bertolini L, Duan J (2015) The effects of the high-speed railway on urban development: international experience and potential implications for China. Prog Plan 98:1–52. https://doi.org/10.1016/j.progress.2013.11.001
Zhang N, Hwang B, Deng X, Ning Y (2020) Achieving transient competitive advantage in high-speed rail projects bidding: Sustainable development perspective. Sustain Dev 28:1738–1754. https://doi.org/10.1002/sd.2121
Zhao C, Wang B (2022) How does new-type urbanization affect air pollution? Empirical evidence based on spatial spillover effect and spatial Durbin model. Environ Int 165:107304. https://doi.org/10.1016/j.envint.2022.107304
Zhao R, Fang C, Liu J, Zhang L (2022) The evaluation and obstacle analysis of urban resilience from the multidimensional perspective in Chinese cities. Sustain Cities Soc 86:104160. https://doi.org/10.1016/j.scs.2022.104160
Zheng L, Long F, Chang Z, Ye J (2019) Ghost town or city of hope? The spatial spillover effects of high-speed railway stations in China. Transp Policy 81:230–241. https://doi.org/10.1016/j.tranpol.2019.07.005

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## Author contributions
SZ conceptualization, writing - original draft; XF data curation, formal analysis, methodology, writing - original draft; LW data curation, formal analysis, writing - review & editing; YC conceptualization, data curation, project administration, writing - original draft, writing - review & editing. All authors read and approved the final manuscript.

## Competing interests
The authors declare no competing interests.

## Ethical approval
This article does not contain any studies with human participants or animals performed by any of the authors. Ethical approval was not required as the study did not involve human participants.

## Informed consent
This article does not contain any studies with human participants performed by any of the authors.

## Additional information
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