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Transportation infrastructure and regional resource allocation

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ABSTRACT

The crux of China's economic growth decline lies in the spatial misallocation of resources, with administrative forces impeding the market flow of production factors and leading to a deterioration in the efficiency of resource allocation. Therefore, China is strongly promoting the implementation of a unified market to break the restrictions imposed by administrative forces on the flow of production factors, give full play to the decisive power of the market in terms of resource allocation, and promote market integration and the cross-regional reallocation of production factors. In this study, we verified the micro effects of transportation accessibility on regional resource allocation efficiency and their internal mechanisms using theoretical and empirical analyses based on data from 282 cities in China from 2005 to 2021. We found that improved transportation infrastructure helps improve regional resource allocation efficiency and generates positive spatial spillovers to neighboring regions. Regarding intrinsic mechanisms, an improved transportation infrastructure can improve regional resource allocation efficiency by inducing industrial agglomeration or alleviating market segmentation. Heterogeneity analysis revealed that improved transportation infrastructure makes the resource allocation efficiency of eastern cities more dependent on market integration effects. In contrast, central and western cities depend more on industrial agglomeration. Meanwhile, transportation infrastructure optimizes resource allocation better in highly compact cities.

1. Introduction

As one of the basic economic components of human society, transportation infrastructure can accelerate the speed of the cyclic movement of means of production among human social groups. Such infrastructure has been created and gradually developed to facilitate the spatial displacement of labor and means of production (Liu et al., 2024; Palmer, 2024). Through transportation infrastructure, humans can break through spatial restrictions and realize the spatial movement of capital, materials, and people, thereby coordinating the interrelationships of human societies between different locations.

The beginning of the comprehensive construction of the world's transportation infrastructure can be traced back to the Industrial Revolution of the 18th century, which was also a golden age for the rapid economic development of humankind. The 18th century Industrial Revolution promoted the rise of industrialization and transportation, which led to the large-scale development of the transportation infrastructure of countries in Europe and America. The climax of the construction of the canal network that emerged at that time is a clear example of this development. In the early 19th century, the successful opening of the Stockton-Darlington and Manchester-Liverpool railroads in the United Kingdom marked the beginning of the railroad construction period in continental Europe. In the late 19th century, the United States built four transcontinental railroads, establishing the world's greatest total railroad length at the time. The improvement of the railroad network greatly broadened the coal mining industry, iron and steel industry, and development of manufacturing spaces, including a series of "station-type" industrial centers and large cities along the railroad, especially in railroad hub areas. Gradual improvement also greatly promoted the rapid development of the railroad transportation economic zone.

In the 20th century, the popularity of automobiles and further development of transportation infrastructure enhanced new spaces. During this period, the widespread implementation of highways and intermodal transportation made the road network much denser than river transportation and railroads, and expanded opportunities for

Abbreviations: IA, industrial agglomeration; MS, market segmentation.

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regional economic development. The subsequent rise of the aviation industry in the last decade has led to new industries such as electronics and electrical appliances being located in the vicinity of large international airports, which has once again contributed to the formation of the transportation network infrastructure characteristics of the new era. It is evident that improved transportation infrastructure not only promotes interregional connectivity, and economic and social development, but also helps accelerate the flow of resources and factors, and balance regional differences in factor development (Banerjee et al., 2020).

Currently, China is in the "pain period" of factor structural adjustment, which is mainly characterized by the diminishing marginal effect of factor inputs and increasing demands on the factor flow environment (Guo et al., 2021). This is particularly reflected in the imbalance between the geographical distribution of China's factor resources and its level of development, which has led to the inefficient flow and utilization of resources throughout the country. Additionally, the "Baumol's disease" caused by insufficient resource inputs in the production services and high technology industries has also made it difficult to optimize the overall resource allocation structure (Kander, 2005). Additionally, the realities of local protectionism, regional barriers, industrial monopolization, and market segmentation (MS) have hindered the effective allocation of factor resources in the Chinese market (Barwick et al., 2021). In this process, transportation infrastructure, as an important basic element of market circulation (Meng et al., 2024), can reduce trade costs by compressing space-time distances and the market demand to pull the effective scale, thereby enhancing the efficiency of market operations (Dou et al., 2024).

Based on these considerations, the main question to ponder is whether an improved transportation infrastructure can facilitate the movement of production factors and improve overall operational efficiency. Additionally, can it facilitate the cross-regional circulation of factor resources–that is, does it have spatial spillover or border effects? Can transportation networks remove market barriers and obstacles to factor mobility? Does geographical heterogeneity characterize this effect? The answers to these questions are of great theoretical significance for an in-depth understanding of the resource allocation effects of transportation infrastructure construction.

Compared with existing studies, we seek to contribute to the literature as follows.

First, based on the principle of new economic geography, we constructed a two-region spatial economics model by introducing transportation infrastructure and conducted a theoretical derivation of the model to study the direct, indirect, and spatial effects of the construction of transportation infrastructure on regional resource allocation. Second, we integrated classical location theory, market location theory, and spatial interaction theory to construct a new system of transportation infrastructure that more accurately portrays the actual level of transportation infrastructure. Third, by incorporating the spatial attributes shared by both transportation infrastructure and regional resource allocation into the same analytical framework, we addressed an important gap in research methodology in international studies. Fourth, we theoretically derived and empirically tested the micro effects of transportation infrastructure on regional resource allocation efficiency and evaluated multidimensional internal mechanisms, providing a micro infrastructure and theoretical reference for future studies.

The remainder of this paper is organized as follows: we first provide a review of the existing literature, theoretical analysis, and research hypotheses. We then present econometric modeling, data processing, and methods. Later, we scrutinize the regression outcomes. Next, regression results are discussed. We present our conclusions and discuss implications in the final section.

2. Literature review

2.1. Regional resource allocation

Krugman's new economic geography explains changes in spatial economic structure under the two-sector framework, arguing that the agglomeration and diffusion of the spatial allocation of regional resources are the result of the joint action of agglomeration and dispersion forces, and dynamic equilibrium. In terms of the connotation of economics, resource allocation efficiency describes how to maximize economic benefits or social welfare through the rational allocation and utilization of these resources under conditions with limited resources (Palmer, 2024; Young, 2000). The use of interregional factor flows can realize the reconfiguration and efficient integration of innovative resources in the inflowing regions (Collard-Wexler & De Loecker, 2015) and solve the problem of wastefulness and under-utilization of resources in the regions out of which innovative factors are exported to promote the effective allocation of national resources. These are the characteristics of regional resource allocation, which flows from regions with a low level of marginal output to regions with a high level of marginal output (Song et al., 2011).

In recent years, research on optimizing resource allocation has been conducted at two levels: indicator measurement and the analysis of influencing factors. From the perspective of indicator measurement, existing studies have mainly utilized factor input and output, discrete element analysis data envelopment methods, etc. for estimation (Brandt et al., 2013; Melitz & Polanec, 2015; Tao et al., 2021; Wei et al., 2000). In studying the resource mismatch problem, the work of Hsieh and Klenow (2009), which is commonly abbreviated as HK, is particularly representative, and our study is mainly based on the HK model. They provided a specific measure of resource misallocation through a composite evaluation based on a specific measure of the extent of capital factor distortions and labor misallocation, which is used as a backward-looking proxy for resource allocation efficiency. Based on this framework, Wang et al. (2020) used differences in regional factor market development to indicate the degree of resource misallocation. Through the analysis of influencing factors, the literature has explored the optimization of resource allocation efficiency from the perspectives of national governance systems, network infrastructure construction, digital empowerment, financing constraints, industrial agglomeration (IA), and trade liberalization (Banerjee & Moll, 2010; Brandt et al., 2013; Melitz, 2003; Restuccia & Rogerson, 2013).

The previous phase of research focused on resource mismatch as a "black box", measuring the extent of resource mismatch and its relationship with economic efficiency. Fewer studies have focused on the impact of factors within the economic system on regional resource allocation, and one of the more influential studies that can be found is Asturias et al. (2014) using data from the Golden Quadrilateral Highway in India to explore the impact on resource allocation. This provides important insights for us to systematically explore the optimization of regional resource allocation from the perspective of transportation infrastructure.

2.2. Transportation infrastructure

Transportation infrastructure is a public resource of productive inputs that can be shared within or between cities. It promotes positive externalities from various factors of production and economic behavior, reducing the costs for economic units within or between cities (Palmer, 2024). Some scholars have examined the impact of transportation infrastructure on economic and social values from a new economic-geographical perspective. For example, Baum-Snow et al. (2017) constructed a corporate transportation road index to examine its impact on urban form in Chinese cities, while Barzin et al. (2018) studied the impact of high-speed rail construction on firm productivity and resource misallocation.

The essence of transportation infrastructure lies in the ease of moving from one region to another, considering transportation costs (distance, time, cost, psychology, etc.; Dou et al., 2024). Based on different research perspectives, the representative definitions and measures of transportation infrastructure can be summarized as shown in Table 1. The evolution of the concept of transportation infrastructure shows that transportation infrastructure contains both spatial and temporal attributes, and the measurement dimensions are increasing. Based on summarizing the previous literature, it is of practical value to measure and evaluate the transportation infrastructure of cities from a three-dimensional perspective. This also paves the way for subsequent studies on transportation infrastructure and regional resource allocation or regional economic activities.

2.3. Spatial and allocation effects of transportation infrastructure improvements

Generally, improvements in transportation infrastructure can significantly reduce transportation costs and time requirements (Dou et al., 2024; Rivera et al., 2014). As market transportation becomes more efficient and economical, firms become more inclined to concentrate on specific regions to take advantage of their proximity to reduce costs and improve their responsiveness to market changes (Majewska, 2015; Meng et al., 2024). Additionally, improved transportation infrastructure allows firms to reach a wider range of markets more easily, including raw material suppliers and consumer markets (Qin, 2017; Wang et al., 2024). This ability to access a wider range of markets has prompted firms to cluster in areas with easy access to transportation to acquire resources and distribute products more efficiently (Donaldson, 2018). The resulting trend of industrial concentration leads to IA, which attracts more related enterprises and service providers to move in, thereby forming larger IAs. The industrial agglomeration effect improves efficiency by optimizing resource allocation. In agglomerated areas, firms can share resources, such as the common use of infrastructure and services, thereby reducing duplicate investments (Dou et al., 2024). Such resource sharing and synergies reduce resource waste and optimize overall resource allocation (He et al., 2022).

Improved transportation infrastructure simultaneously facilitates economic linkages between different regions (Liu et al., 2024; Palmer, 2024; Wang & Wang, 2024), enabling the movement of resources, goods, and services between a wider range of markets. Such strengthened linkages break geographical constraints and promote interregional market integration (Holl, 2016; Meng et al., 2024). With deeper market integration, resources can be reallocated and optimized on a wider scale according to market demand, thereby improving overall resource allocation efficiency. Additionally, improved transportation infrastructure makes supply chain management more efficient, as firms can easily obtain raw materials and quickly deliver products to consumers (Wang et al., 2024; Zheng & Kahn, 2013). This supply chain optimization reduces inventory costs and improves the efficiency of production and distribution processes, thereby increasing the overall efficiency of resource allocation (Dou et al., 2024). Furthermore, increased transportation infrastructure broadens market reach, providing a wider market for companies to sell in and a wider variety of products for consumers to choose from (Chacon-Hurtado et al., 2020; Meng et al., 2024). Expanding the market scope allows resources to be allocated efficiently over a wider range according to market forces, thereby improving the efficiency of the overall market. Finally, improved transportation infrastructure directly reduces transaction costs, including transportation and time costs (Barzin et al., 2018; Dou et al., 2024). Such cost reductions allow markets to operate more efficiently and flexibly by allocating resources in response to market changes.

In addition, there may be spatial effects, heterogeneity and variability in the regional resource allocation of transportation infrastructure development. For example, Yu et al. (2022) adopted a spatial perspective to examine equity issues embedded in the urban built environment, finding that spatial inequalities across the urban-rural gradient are evident in walkability and air pollution exposure. Yu et al. (2023) effectively identified the spatial heterogeneity of urban compactness on ecosystem services using a geographically weighted model. He et al. (2023) found significant spatial stratification heterogeneity in the level of urban development under different urban growth patterns.

A review of the above literature revealed that, first, studies related to China's regional economy tend to focus on judging the degree of regional economic integration. Few studies have considered transportation infrastructure and its spatial attributes in a research framework to analyze its impact on the regional economy. Additionally, with the development of modern location theory, the measurement of the transportation infrastructure index should be further improved based on existing theories, rather than solely relying on classical location theory or market location theory and measuring this concept one-sidedly. Second, scholars have paid some attention to the impact of transportation infrastructure on regional economic behavior but have not explored its mechanisms of influence in depth, and research perspectives are largely one-dimensional, lacking a unified theoretical framework. Third, the existing literature seldom discusses the optimization effect of differentiated resource allocation in the eastern and mid-western regions from the perspective of regional heterogeneity. It also lacks a test for the path heterogeneity of the optimization effect of resource allocation.

Table 1
Representative definitions of transportation infrastructure.

Representative Definition and Measurement	References
Impacts of geography and distance on individual trips	Hagerstrand (1974)
Costs that arise in society as a direct result of individuals and as a by-product of society as a whole, such as traffic congestion and environmental pollution	Vickerman (1974)
Degree of freedom of individual participation in activities	Weibull (1976); Linneker and Spence (1992)
Ease of getting from one location in space to another	Dalvi and Martin (1976); Ashworth and Goodall (1990)
Ability to choose a mode of transportation to reach a destination within a certain period of time	Moseley (1979)
Ability to use some mode of transportation to get to or from a specified location within a certain timeframe	Geertman and Ritsema Van Eck (1995)
Urban space is the totality of the geographic relationship between city dwellers and their socioeconomic activities	Shen (1998)

3. Theoretical analysis and research hypotheses

Assume that the economic system consists of region z and region r. Then, the utility for consumers in region z can be expressed as:

$$U_z = C_z^{\lambda} D_z^{1-\lambda}, 0 < \lambda < 1 \tag{1}$$

where C_z and D_z denote the product index and illiquid consumption facility, respectively, where C_z can be expressed as:

$$C_z = \left[\sum_{r=1}^{R} \psi_{zr} Đ_{zr}^{\frac{\sigma-1}{\sigma}} \right]^{\frac{\sigma}{\sigma-1}} \tag{2}$$

where ψ_{zr} denotes the number of consumer-induced increases in cross-region vendors and $Đ_{zr}$ denotes the number of products consumed across regions.

$$Đ_{zr} = \int_{i}^{\infty} q_r(i)^{\frac{\sigma-1}{\sigma}} di \tag{3}$$

Assume that there is $\phi(\tau_{zr})$ loss of transportation resources for transporting $[\phi(\tau_{zr}) - 1]$ quantities of products from region r to region z. Then, $\phi(\tau_{zr})$ can be defined as:

$$\phi(\tau_{zr}) = \phi_{zr}^1 - \phi_{zr}^2 = f(Border_{zr}, d_{zr}, \varepsilon) \tag{4}$$

where ϕ_{zr}^1 is the initial transportation volume between regions z and r, and ϕ_{zr}^2 is the unit resource loss saved by an increase in the infrastructure index. When z and r are engaged in factor exchange or trade, $Border_{zr}$ is equal to one. When the two regions do not interact across the border and only engage in factor exchange or trade within their own region, $Border_{zr}$ is equal to zero. d_{zr} is the geographic distance and ε denotes outside influences, including institutions, cultures, and types of dialects.

Drawing on the research of Redding and Sturm (2008), we define the transportation infrastructure index η_{zr} for regions z and r as:

$$\eta_{zr} = \sum_{i \in N} \psi_{zr} [P_r \phi(\tau_{zr})]^{1-\sigma} \tag{5}$$

where p_{zr} and q_{zr} are the delivery price and quantity, respectively. Let the total revenue of region z be Y_z, and let the region purchase the traded product at a rate of μ_z. Maximizing utility by solving for utility U_z yields:

$$q_{zr} = \psi_{zr}{}^{\sigma-1} \left(\frac{\phi(\tau_{zr}) p_r}{P_z} \right)^{-\sigma} \frac{\mu_z Y_z}{P_z} \tag{6}$$

$$P_z = \left[\sum_{z=1}^{R} \psi_{zr} (p_{zr})^{1-\sigma} \right]^{\frac{1}{1-\sigma}} = \eta_{zr}{}^{\frac{1}{1-\sigma}} \tag{7}$$

The vendor profit function can be set as:

$$\pi_r = p_r q_r - \omega_r (F + l_m q_r) \tag{8}$$

The equilibrium price is obtained from the following profit maximization condition:

$$P_{zr} = \left(\frac{\sigma}{\sigma - 1} \right) l_m \omega_r \tag{9}$$

The labor input and equilibrium production per unit of output are respectively defined as:

$$l_m = \frac{\phi(\tau_{zr})}{z} \tag{10}$$

$$q_r = zF(\sigma - 1) \tag{11}$$

When the labor force in the two regions achieves equilibrium, the difference between the actual and optimal output sizes is:

$$Resmis = \frac{\left(\frac{\sigma}{\sigma-1} \right) \frac{\phi(\tau_{zr})}{z} \omega_r z F(\sigma - 1)}{\eta_{zr}{}^{\frac{1}{1-\sigma}} \psi_{zr}{}^{\sigma-1} \left(\frac{\phi(\tau_{zr}) p_r}{P_z} \right)^{-\sigma} \frac{\mu_z Y_z}{P_z}} = \frac{\sigma \phi(\tau_{zr})^{\sigma+1} p_r{}^{\sigma} \omega_r F}{\psi_{zr}{}^{\sigma-1} \mu_z Y_z} \cdot \eta_{zr}{}^{\frac{\sigma}{1-\sigma}} \tag{12}$$

According to Eq. (12), the larger the transportation infrastructure index (η_{zr}) and the smaller the resource misallocation, the more efficient the resource allocation is, while other factors are kept constant (elasticity of substitution between products $\sigma \geq 1$). This leads to research hypothesis 1.

Hypothesis 1. Improved transportation infrastructure contributes to more efficient regional resource allocation.

We assume that the flow of resource elements from region z to r can be expressed as follows:

$$W_{zr} = N_r p_{zr} q_{zr} \tag{13}$$

where N_r is the type of resource factor in region r, and $p_{zr}$and q_{zr} denote the price and quantity of factors, respectively. These values can be obtained by associating Eqs. (6), (7), and (13) as follows:

$$W_{zr} = \frac{W_r}{q_r} \left[\frac{\phi(\tau_{zr})}{\psi_{zr}} \right] \left(\frac{P_r}{P_z} \right)^{-\sigma} \left(\frac{\mu_z Y_z}{P_z} \right) = \frac{W_r}{q_r} \frac{\phi(\tau_{zr})}{\psi_{zr}} \left[\frac{P_r}{\eta_{zr}{}^{\frac{1}{1-\sigma}}} \right]^{-\sigma} \left[\frac{\mu_z Y_z}{\eta_{zr}{}^{\frac{1}{1-\sigma}}} \right] \tag{14}$$

Taking the logarithm yields:

$$lnW_{zr} = lnP_z{}^{\sigma-1} + ln\mu_z Y_z + lnW_r - (\sigma - 1) ln \frac{\phi(\tau_{zr})}{\psi_{zr}} - \sigma ln P_r \tag{15}$$

$$lnP_z{}^{\sigma-1} = (\sigma - 1) ln \left(\sum_{z=1} \sum_{r=1} \psi_{zr} W_{zr} \right) \tag{16}$$

where $\frac{\phi(\tau_{zr})}{\psi_{zr}}$ can be considered as factor flow costs in a broad sense.

Substituting Eq. (16) into Eq. (15) yields:

$$lnW_{zr} = (\sigma - 1) ln \left(\sum_{z=1} \sum_{r=1} \psi_{zr} W_{zr} \right) + ln\mu_z Y_z + lnW_r - (\sigma - 1) ln \frac{\phi(\tau_{zr})}{\psi_{zr}} \tag{17}$$

According to Eq. (17), the larger the consumer-induced increase in the number of cross-region manufacturers (ψ_{zr}), the greater the factor of replacement or trade, while other factors remain constant (elasticity of substitution between products $\sigma \geq 1$). Eq. (12) indicates that the larger the consumer-induced increase in the number of cross-regional vendors (ψ_{zr}), the greater the increase in the transportation infrastructure index (η_{zr}), which further improves the degree of resource misallocation, which in turn improves the efficiency of regional resource allocation. This leads to hypothesis 2.

Hypothesis 2. Improved transportation infrastructure leads to IA, which increases regional resource allocation efficiency.

Substituting Eq. (4) into Eq. (17) yields:

$$\begin{aligned} lnW_{zr} = {} & (\sigma - 1) ln \left(\sum_{z=1} \sum_{r=1} \psi_{zr} W_{zr} \right) + ln\mu_z Y_z + lnW_r \\ & - (\sigma - 1) ln \frac{f(Border_{zr}, d_{zr}, \varepsilon)}{\psi_{zr}} - \sigma ln P_r, \end{aligned} \tag{18}$$

where $Border_{zr}$ refers to all barriers to interregional factor flows in general, including cultural preferences and resource flow losses. Clearly, $f(Border_{zr}, d_{zr}, \varepsilon)$ is an increasing function, and the greater the factor circulation barriers, the more unfavorable it is for factor allocation. Improvements in transportation infrastructure can significantly increase the level of market integration, leading to hypothesis 3.

Hypothesis 3. Improved transportation infrastructure reduces fragmentation and promotes market integration, thereby increasing the efficiency of regional resource allocation.

Based on the above analysis, the theoretical framework considered in our study is presented in Fig. 1.

4. Research design

4.1. Econometric modeling

To study the impact of transportation infrastructure on the efficiency of regional resource allocation, a fixed-effects model was established as follows:

$$Resmis_{it} = \alpha_0 \eta_{zrit} + \alpha_1 \sum Control + \mu_t + \eta_t + \varepsilon_{it} \tag{19}$$

Here, $Resmis_{it}$ is the degree of resource misallocation in city i in year t, η_{zrit} is the level of transportation infrastructure in city i in year t, μ_t is the year fixed effect controlling for different year characteristics, η_i is the city fixed effect controlling for city characteristics, and ε_{it} is a random

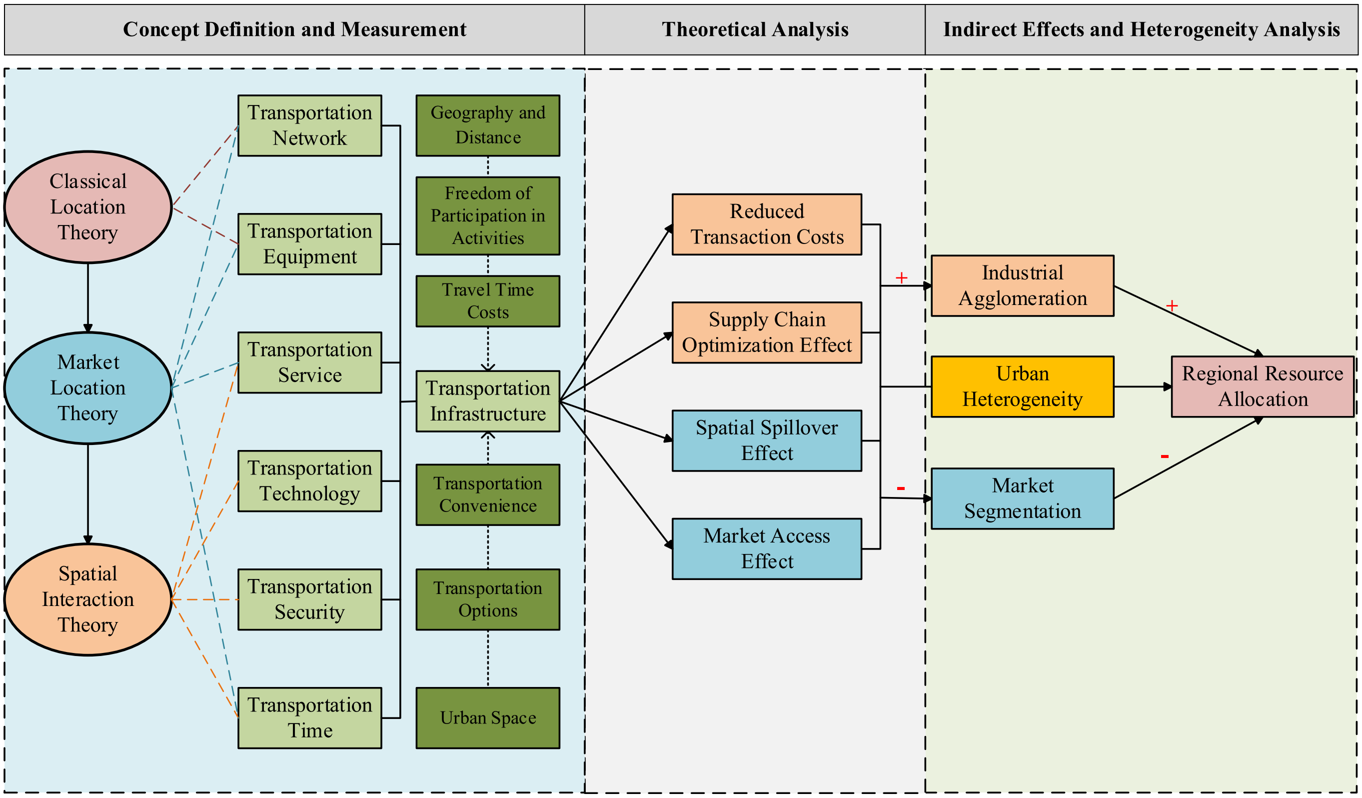

Fig. 1. Theoretical framework.

error term.

To investigate whether transportation infrastructure has spatial spillover effects on resource allocation efficiency in local and spatially related areas based on spatial economics, the following spatial econometric model was established:

$$Resmis_{it} = \rho W_{ij} Resmis_{it} + \alpha \eta_{zrit} + \beta W_{ij} \eta_{zrit} + \gamma Control_{it} + \varphi W_{ij} Control_{it} + \mu_t + \eta_t + \varepsilon_{it}. \tag{20}$$

Here, ρ is the spatial autocorrelation coefficient and W_{ij} is the spatial matrix. We selected four different spatial matrices, namely a 0–1 adjacency matrix, geographic distance matrix, economic distance matrix, and economic-geographic nested matrix, to avoid matrices with missing unobservable features.

Our theoretical analysis indicates that an improvement in transportation infrastructure will lead to IA, reduce the level of MS, and improve the efficiency of regional resource allocation. Therefore, based on the mediation effect model, we further explore the specific mechanisms through which transportation infrastructure impacts regional resource allocation efficiency.

$$(IA, MS)_{it} = \beta_0 \eta_{zrit} + \beta_1 Control_{it} + \mu_t + \eta_t + \varepsilon_{it} \tag{21}$$

$$Resmis_{it} = \theta_0 \eta_{zrit} + \theta_1 (IA, MS)_{it} + \theta_2 Control_{it} + \mu_t + \eta_t + \varepsilon_{it} \tag{22}$$

4.2. Variables

4.2.1. Regional resource allocation (Resmis)

We refer to Aoki (2012), who used regional resource misallocation to measure resource allocation efficiency. It should be noted that the higher the degree of regional resource misallocation, the lower the resource allocation efficiency.

First, we construct the following production function with constant returns to scale:

$$Y_i = A_i K_i^{\alpha_i} L_i^{1-\alpha_i} \tag{23}$$

Then, the profit maximization problem can be expressed as:

$$Max: \pi_i = P_i F_i(K_i, L_i) - \left(1 + \tau_{L_i}\right) P_L L_i \tag{24}$$

$$s.t. \alpha_i P_i Y_i = \left(1 + \tau_{K_i}\right) P_K K_i \tag{25}$$

$$(1 - \alpha_i) P_i Y_i = \left(1 + \tau_{K_i}\right) P_K K_i \tag{26}$$

$$K = \sum\nolimits_i K_i, L = \sum\nolimits_i L_i \tag{27}$$

Total regional output is defined as:

$$Y = \sum\nolimits_i P_i Y_i \tag{28}$$

Based on Eqs. (21)–(25), the capital input K and labor input L must satisfy the following:

$$K_i = \frac{\delta_i \alpha_i \frac{1}{1+\tau_{K_i}}}{\sum_j \delta_j \alpha_j \frac{1}{1+\tau_{K_j}}} K \tag{29}$$

$$L_i = \frac{\delta_i (1 - \alpha_i) \frac{1}{1+\tau_{L_i}}}{\sum_j \delta_j (1 - \alpha_j) \frac{1}{1+\tau_{L_j}}} L \tag{30}$$

where $\delta_i = \frac{P_i Y_i}{Y}$. We construct the coefficients of capital and labor distortion for city i as:

$$\rho K_i = \frac{1}{1 + \tau_{K_i}}, \rho L_i = \frac{1}{1 + \tau_{L_i}} \tag{31}$$

Substituting Eq. (29) into Eqs. (27) and (28) yields:

$$K_i = \frac{\delta_i \alpha_i}{\alpha} \cdot \frac{\rho K_i}{\sum_j \frac{\delta_j \alpha_j}{\alpha} \rho K_j} \cdot K \tag{32}$$

$$L_i = \frac{\delta_i(1-\alpha_i)}{1-\alpha} \cdot \frac{\rho L_i}{\sum_j \frac{\delta_j(1-\alpha_j)}{1-\alpha} \rho L_j} \cdot L \tag{33}$$

We respectively denote capital misallocation and labor misallocation as:

$$\tau_{K_i} = \frac{1}{\frac{K_i}{K} \Big/ \frac{\delta_i \alpha_i}{\alpha}} - 1 \tag{34}$$

$$\tau_{L_i} = \frac{1}{\frac{L_i}{L} \Big/ \frac{\delta_i(1-\alpha_i)}{1-\alpha}} - 1 \tag{35}$$

Then, the resource misallocation index for city i is:

$$Resmis_i = \alpha_i \tau_{K_i} + (1-\alpha_i)\tau_{L_i} \tag{36}$$

4.3. Transportation infrastructure (η_{zr})

Research on the measurement of transportation infrastructure can be broadly categorized into three groups. First, in classical location theory, the transportation infrastructure index is used to measure the degree of difficulty of overcoming the nodes that block each node in space, so the basic transportation network and transportation equipment such as highway networks, railroad networks, and passenger buses within or between cities are the basis of evaluation. This is the measurement adopted in most studies (Ashworth & Goodall, 1990; Dalvi & Martin, 1976).

Second, in market location theory, the transportation infrastructure index is used to measure the additional benefits that individuals receive through utility choices at a given opportunity cost threshold (Lösch, 1938). This also means that market location theory considers the differentiated utility of consumers in choosing different transportation modes or services, including related road services, emergency rescue, and administrative penalty intensity, based on classical location theory. Market location theory also considers vested gains from trade or circulation, such as the passenger throughput of different modes of transportation and the volume of the express delivery business.

Third, in spatial interaction theory, the transportation infrastructure index is used to measure the infrastructure of specific transportation network services to individuals from one region to another activity region, or the opportunities for socioeconomic and technological exchanges between activity regions (Linneker & Spence, 1992). For example, car networking companies and electronic toll collection (ETC) lanes can provide specific transportation network services. Additionally, key national transport laboratories, and research and development centers established in China are continuously promoting scientific and technological advances in transport infrastructure. Spatial interaction theory is an important complement to modern location theory, which considers the important role of transportation science and technological advancement in the development of transportation infrastructure.

Considering these perspectives, we construct an evaluation index system based on six dimensions: transportation network, equipment, service, technology, security, and traffic travel time (as shown in Table 2). To refine these indicators, we measure the transportation infrastructure by density, specifically including highway network density, expressway network density, high-speed rail operation density, and inland waterway density, and the percentage of investment in fixed assets for transportation is added to represent the stock situation of the construction of transportation infrastructure. The amount of transportation equipment that can be obtained to reach a particular activity place is also considered, which mainly includes passenger and freight car ownership, and airport takeoff and landing (Linneker & Spence, 1992). We consider the number of transportation services as well, and the detailed indicators mainly include the throughput of various transportation modes (Harris, 1954). Transportation technology and transportation safety are incorporated into the indicator system, including the number of car networking enterprises, the number of key transportation laboratories and R&D centers, and the satisfaction of emergency rescue. Regarding traffic travel time, the relative attractiveness of nodes is captured by referring to Diao's (2018) and Albacete et al.'s (2017) weighted average travel time.

Table 2
Transportation infrastructure indicator system.

Primary indicator	Secondary indicator	Direction
Transportation network	Density of highway network	+
	Density of railroad operations	+
	Density of high-speed rail operations	+
	Density of inland waterways	+
	Percentage of investment in transportation fixed assets	+
Transportation equipment	Freight car ownership	+
	Passenger car ownership	+
	Airport movements	+
	Percentage of persons employed in transportation	+
	Number of transportation equipment patents	+
Transportation service	Rail passenger turnover	+
	Air passenger throughput	+
	Air cargo and mail throughput	+
	Road freight turnover	+
	Express business volume	+
	Number of automobile self-driving sports camps	+
Transportation technology	Number of telematics companies	+
	Number of transportation science and technology institutions	+
	Number of key transport laboratories and R&D centers	+
	Percentage of ETC lane modifications	+
Transportation security	Satisfaction with emergency response	+
	Number of administrative penalties for traffic safety	−
Traffic travel time	Average travel time	−

To overcome the issue of non-determinable weights, we adopted the CRITIC-TOPSIS method to measure the transportation infrastructure level comprehensively as follows.

There were m evaluation objects and n evaluation indicators, and the original data X_{ij} and $i = 1, \ldots, m; j = 1, \ldots, n$ were processed without dimensions.

$$X_{ij}' = \frac{X_j - X_{\min}}{X_{\max} - X_{\min}}, X_{ij}' = \frac{X_{\max} - X_j}{X_{\max} - X_{\min}} \tag{37}$$

We calculated the amount of information for the indicator j as:

$$C_j = \frac{\sigma_j}{\overline{X_j}} \sum_{i=1}^{m} \left(1 - |r_{ij}|\right) \tag{38}$$

We calculated the weight of the indicator j as:

$$w = \frac{C_j}{\sum_{j=1}^{m} C_j} \tag{39}$$

Using the TOPSIS model, the weighting matrix was calculated as:

$$V = \begin{bmatrix} v_{11} & \cdots & v_{1n} \\ \vdots & \ddots & \vdots \\ v_{m1} & \cdots & v_{mn} \end{bmatrix} \tag{40}$$

The distance between the positive ideal solution and negative ideal solution is written as:

$$V = (v_1, v_2, \ldots, v_n) = \left\{ max\, v_{ij} \middle| j \in J_1, min\, v_{ij} \middle| j \in J_2 \right\}, \tag{41}$$

where J_1 is the set of benefit-based indicators and J_2 is the set of cost-based indicators.

The distances from the evaluation object to the positive and negative ideal solutions were calculated as:

$$s_i^+ = \sqrt{\sum_{j=1}^{n}\left(v_{ij} - v_j^+\right)^2}, s_i^- = \sqrt{\sum_{j=1}^{n}\left(v_{ij} - v_j^-\right)^2}. \tag{42}$$

The relative fitness of the evaluation object *i* compared with the ideal solution is:

$$\delta_i = \frac{s_i^-}{s_i^+ + s_i^-}. \tag{43}$$

Ranking is performed based on the magnitude of the δ_i value, with larger values indicating closer proximity to the optimal level.

4.4. Mechanistic variables

The mechanistic variables are IA and MS. We calculated the IA level using location entropy and the number of employees in the second and third industries as output indicators (Fan & Scott, 2003; He et al., 2022). To measure MS, we selected the relative price change variance of the consumer price index, fixed asset investment price index, and average real wage index of employees in each city to measure consumer MS, capital MS, and labor MS, respectively, following the principal component analysis method (Parsley & Wei, 2001).

4.5. Control variables

Based on the findings of previous studies, industrial structure (Str), foreign direct investment (FDI), government intervention (Gov), and urbanization rate (Urb) were selected as control variables. Industrial structure is measured as the ratio of the added value of secondary and tertiary industries, foreign trade dependence is measured as the total amount of import and export trade, the level of government intervention is mainly measured as the percentage of government fiscal expenditure in the current year, and the urbanization rate is measured as the proportion of the urban population among the total population.

4.6. Data sources and processing

We select a sample of 282 cities in China from 2005 to 2021, excluding those with more severe missing values. The geographical location of the sample city is shown in Fig. 2. We obtained data from the China Statistical Yearbook, China Urban Statistical Yearbook, and China Urban Transportation Green Development Report. Missing values in some of the city samples were filled in by linear interpolation. Descriptive statistics for each variable are listed in Table 3.

Fig. 2. The geographic location of the city samples.

Table 3
Descriptive statistics.

Symbol	Obs	Mean	Standard error	Min	Max
Resmis	4794	1.2012	0.4218	0.0015	2.9014
η_{zr}	4794	0.2657	0.1328	0.0004	0.8028
Str	4794	1.1407	0.6535	0.4996	5.4244
FDI	4794	0.2788	0.3207	0.0070	1.7076
Gov	4794	0.3680	0.1917	0.0792	1.3791
Urb	4794	0.5483	0.1674	0.1025	0.8660
IA	4794	0.8258	0.2391	0.1638	1.2647
MS	4794	0.3406	0.2430	0.0352	3.1420

5. Empirical analysis

5.1. Relevance analysis

Table 4 describes the Pearson correlation coefficients between the main variables. The correlation coefficients of the main variables are all <0.5, indicating no multicollinearity problem. The correlation coefficient between transportation infrastructure and resource misallocation is −0.132 and is statistically significant at the 1 % level, indicating that improving transportation infrastructure can alleviate resource misallocation and improve the efficiency of regional resource allocation. Further observations indicate that transportation infrastructure, resource misallocation, and IA are all significantly positively correlated, whereas MS is significantly negatively correlated, which is in line with the expectations of our initial theoretical mechanism.

5.2. Baseline regression

Columns (1) to (4) in Table 5 report the fixed-effects regression results. The results reveal that the coefficients of transportation infrastructure (η_{zr}) are −1.1899, −0.6145, −1.0981, and − 0.7885, all of which are significant at the 1 % level. In terms of economic significance, a 1 % improvement in transportation infrastructure can reduce resource misallocation by 0.7885, suggesting that improving transportation infrastructure can effectively alleviate resource misallocation and improve the efficiency of regional resource allocation, and that hypothesis 1 is valid.

5.3. Spatial analysis

Spatial autocorrelation tests were performed on environmental pollution prior to the spatial econometric analysis. Spatial autocorrelation is a method for analyzing the similarity of attribute values within spatial neighborhoods or spatially adjacent regions. Our findings were verified using the currently recognized global Moran's index (He et al., 2022).

$$Moran's\ I = \frac{n}{\sum_{i=1}^{n}(x_i - \overline{x})^2} \frac{\sum_{i=1}^{n}\sum_{j=1}^{n} W_{ij}(x_i - \overline{x})(x_j - \overline{x})}{\sum_{i=1}^{n}\sum_{j=1}^{n} W_{ij}} \tag{44}$$

As shown in Table 6, the global Moran's index of transportation infrastructure from 2005 to 2021 is significant and positive, with values ranging from 0.216 to 0.434. These results indicate that the overall transportation infrastructure index exhibits significantly positive spatial autocorrelation with a relatively strong spatial agglomeration pattern.

The local spatial autocorrelation, which can be tested by the local Moran index (He et al., 2022), is calculated as follows:

$$I_i = \frac{y_i - \overline{y}}{S^2}\sum_{j=1}^{n} W_{ij}(y_i - \overline{y}) \tag{45}$$

Table 4
Spatial econometric regression results.

	Resmis	η_{zr}	Str	FDI	Gov	Urb	IA	MS
Resmis	1							
η_{zr}	−0.132***	1						
Str	0.097**	0.350***	1					
FDI	−0.241***	0.463***	0.102**	1				
Gov	0.032**	−0.354***	0.162***	−0.313***	1			
Urb	0.126***	0.630***	0.472***	0.580***	−0.352***	1		
IA	0.135***	0.084*	0.120***	0.144***	0.111**	−0.024	1	
MS	0.008***	−0.167***	−0.641***	0.138***	−0.617***	0.160***	−0.265***	1

Table 5
Fixed-effects regression results.

Variable	(1)	(2)	(3)	(4)
η_{zr}	−1.1899***	−0.6145***	−1.0981***	−0.7885***
	(0.1335)	(0.1171)	(0.1586)	(0.1131)
Str		0.1865***	0.1378***	0.0588*
		(0.0241)	(0.0261)	(0.0327)
FDI		−0.7465***	0.5967***	−0.4126***
		(0.0651)	(0.0683)	(0.0748)
Gov		0.0934	0.0580	−0.5909***
		(0.1305)	(0.0951)	(0.1485)
Urb		0.0488	0.0434	−2.6940***
		(0.1678)	(0.1768)	(0.3806)
_cons	0.3023***	0.3669***	0.1546	1.6823***
	(0.0326)	(0.0698)	(0.0962)	(0.1884)
City		FE		FE
Year			FE	FE
N	4794	4794	4794	4794
R^2	0.2630	0.4322	0.2869	0.5223

$*p < 0.1$, $**p < 0.05$, $***p < 0.01$.

Table 6
Global Moran's index.

Year	Moran	P	Year	Moran	P
2005	0.216**	0.046	2014	0.427***	0.006
2006	0.226**	0.031	2015	0.344***	0.006
2007	0.269**	0.023	2016	0.368***	0.005
2008	0.312**	0.023	2017	0.421***	0.004
2009	0.365**	0.019	2018	0.372**	0.011
2010	0.250**	0.013	2019	0.434***	0.009
2011	0.411***	0.010	2020	0.429**	0.011
2012	0.416**	0.012	2021	0.405***	0.008
2013	0.512***	0.006			

$$S^2 = \frac{1}{n}\sum_{i=1}^{n}(y_i - \bar{y})^2, \bar{y} = \frac{1}{n}\sum_{i=1}^{n} y_i \tag{46}$$

Fig. 3 shows the local spatial correlation test of transportation infrastructure in 2005, 2010, 2015 and 2021, which shows that China's transportation infrastructure has strong spatial autocorrelation. Through the local Moran scatter plot, it can be observed that the cities located in the first quadrant, i.e., the regions showing "high - high" agglomeration patterns, are mainly composed of large urban agglomerations, and have a tendency to shift from the eastern coastal region to the central and western regions. Cities located in the third quadrant of the Moran scatterplot, i.e. cities with "low-low" agglomeration patterns, are mainly composed of cities in the central and western parts of the country and account for a larger proportion.

Columns (1) to (4) in Table 7 report the test results of the spatial distribution model (SDM). One can see that the coefficients of transportation infrastructure (η_{zr}) are −0.5024, −0.4904, −0.3093, and − 0.4507, which are all significantly negative at the 1 % level, when the transformed 0–1 matrix, geographic distance matrix, economic distance matrix, and economic-geographic nested matrix are considered, respectively. Additionally, the coefficient of transportation infrastructure ($W*\eta_{zr}$) is significantly negatively correlated with resource misallocation, suggesting a positive spatial spillover effect of improved transportation infrastructure on resource misallocation in neighboring cities.

5.4. Robustness check

To ensure the robustness of the benchmark regression results, we conducted the following robustness tests: Columns (1) to (3) in Panel A in Table 8 present the regression results for replacing the explanatory variables. We used the degree of labor allocation distortion to replace the original explanatory variables in the robustness test. The test results reveal that the regression coefficients of transportation infrastructure (η_{zr}) are −0.4574, −1.0523, and − 0.2392, which are all significantly negative at the 1 % level. Columns (4) to (6) present the results of the robustness tests, with all explanatory variables lagged by one period. The regression coefficients of the one-period-lagged transportation infrastructure (η_{zr}) are −1.0976, −0.6917, and − 1.7957, all of which are significantly negative. Overall, the results indicate that transportation infrastructure is significantly negatively correlated with the distortion in the allocation of the labor force, and this conclusion is still valid when the effect of the time lag is considered, which further supports hypothesis 1.

Columns (7) and (8) in Panel B further test the fixed-effects model using the system Gaussian mixture model (GMM) to rule out reverse causal endogeneity. Column (9) presents the results of the system GMM estimation after replacing the explanatory variables with labor allocation distortions. The results reveal that transportation infrastructure (η_{zr}) remains significantly negatively correlated with resource misallocation after excluding endogeneity. Columns (10) to (12) present the GMM estimation of the SDM when selecting ($W*\eta_{zr}$) as the instrumental variable. One can see that transportation infrastructure (η_{zr}) remains significantly negatively correlated, indicating that the spillover effect of transportation infrastructure on resource allocation efficiency in neighboring cities still holds after considering endogeneity.

5.5. Mechanism testing

The regression results of the mechanism tests are presented in Columns (1) to (4) of Table 9. In Columns (1) and (2), the regression coefficient of transportation infrastructure (η_{zr}) on IA is 0.2386, which is significantly positive, indicating that an improvement in transportation infrastructure leads to the agglomeration of industries. The regression coefficients of transportation infrastructure (η_{zr}) and IA on resource misallocation are −0.7104 and − 0.5873, respectively, which are significantly negative. In Columns (3) and (4), the regression coefficient of transportation infrastructure (η_{zr}) on MS is −0.3381, which is significantly negative, indicating that an improvement in transportation infrastructure can significantly increase the level of market integration. The regression coefficients of transportation infrastructure (η_{zr}) and MS on resource misallocation are −0.5243 and 0.1262, respectively, which are significant at 1 % level.

The two-step mediated effects model may suffer from multicollinearity problems, so we refer to He et al. (2022) to use bootstrap

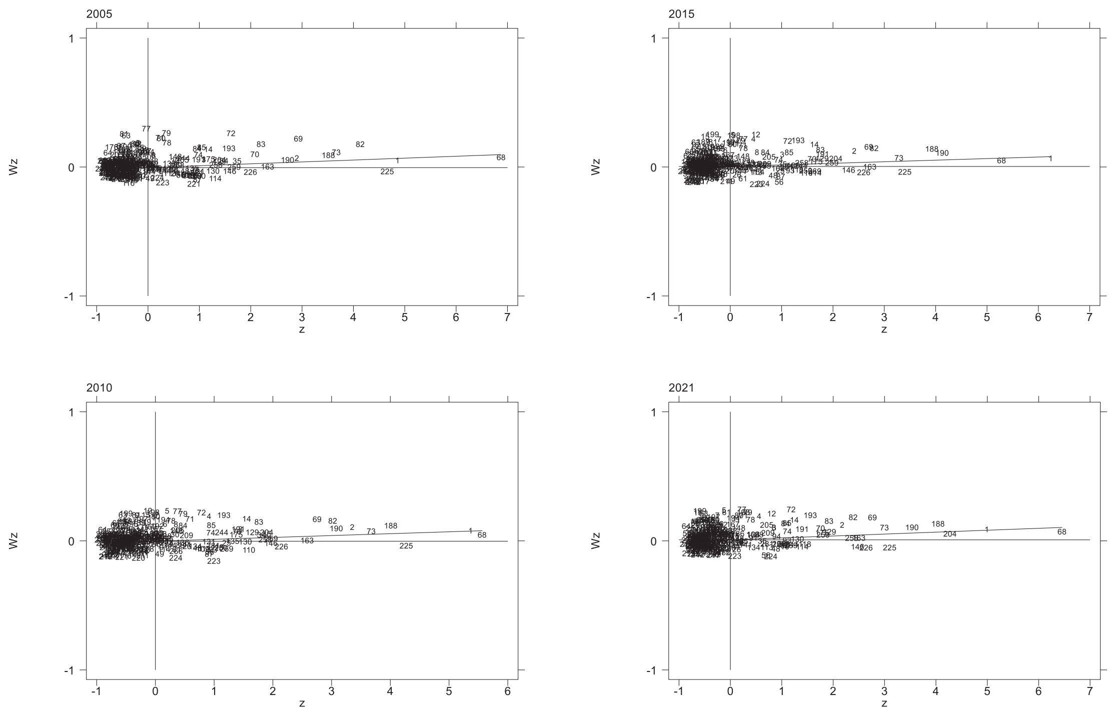

Fig. 3. Local spatial correlation tests[1].

[1] The names of cities in the map are replaced by the administrative code ordering.

Table 7
Spatial econometric regression results.

Variable	(1)	(2)	(3)	(4)
	0–1 Matrix	Geographic distance matrix	Economic-distance matrix	Economic geographic nested matrix
η_{zr}	−0.5024***	−0.4904***	−0.3093***	−0.4507***
	(0.0974)	(0.0952)	(0.1042)	(0.0935)
Str	0.0830***	0.0411	0.0355	0.0712**
	(0.0301)	(0.0302)	(0.0313)	(0.0294)
FDI	−0.4985***	−0.4644***	−0.5570***	−0.4752***
	(0.0677)	(0.0659)	(0.0825)	(0.0650)
Gov	−0.3476**	−0.5918***	−0.5338***	−0.5196***
	(0.1455)	(0.1357)	(0.1395)	(0.1321)
Urb	−3.5191***	−3.9848***	−2.9592***	−3.7787***
	(0.3401)	(0.3562)	(0.3559)	(0.3401)
$W^*\eta_{zr}$	−0.3361**	−0.6860	−0.2362***	−0.3837***
	(0.1391)	(0.6799)	(0.0799)	(0.1880)
*W*Str*	−0.0269	−0.3421*	0.3476***	0.1494
	(0.0650)	(0.1974)	(0.0882)	(0.1633)
*W*FDI*	−0.6855***	−2.0972***	0.9367***	−0.8297**
	(0.1107)	(0.4866)	(0.2388)	(0.3759)
*W*Gov*	0.1147	1.6229	1.2464***	−0.6641
	(0.2435)	(1.1456)	(0.3925)	(1.3533)
*W*Urb*	6.7437***	13.7229***	−3.6860***	14.2854***
	(0.7232)	(2.0560)	(1.1909)	(2.0174)
City-year	FE	FE	FE	FE
rho	−0.0815***	−0.6389***	−0.1096	−0.1454***
	(0.0393)	(0.1865)	(0.0859)	(0.5881)
N	4794	4794	4794	4794
Log-likelihood	379.1220	386.0792	350.8248	394.3677
R^2	0.4006	0.2967	0.0089	0.2639

*$p < 0.1$, **$p < 0.05$, ***$p < 0.01$.

Table 8
Robustness checks.

Panel A: Robustness Check I						
Variable	Substitution of explanatory variables			Explanatory variables lagged one period		
	(1)	(2)	(3)	(4)	(5)	(6)
η_{zr}	−0.4574***	−1.0523***	−0.2392***			
	(0.0818)	(0.1023)	(0.0792)			
$L.\eta_{zr}$				−1.0976***	−0.6917***	−1.7957***
				(0.1869)	(0.1116)	(0.1870)
Control	FE	FE	FE	FE	FE	FE
City-Year	FE			FE		
N	4794	4794	4794	4794	4794	4794
R^2	0.2862	0.3156	0.4311	0.4534	0.3481	0.5665
Panel B: Robustness Check II						
Variable	GMM estimation			GMM estimation of spatial SDM model		
	(7)	(8)	(9)	(10)	(11)	(12)
L.Resmis			1.0420***	0.9932***	1.0076***	0.9882***
			(0.0773)	(0.0158)	(0.0073)	(0.0168)
L2.Resmis		1.2037***				
		(0.0734)				
η_{zr}	−0.0853**	−0.0781*	−0.0634***	−0.0129	−0.0282*	−0.0188**
	(0.0420)	(0.0434)	(0.0276)	(0.0136)	(0.0148)	(0.0107)
$W^*\eta_{zr}$				0.0957**	−0.0119***	−0.0785***
				(0.0396)	(0.0406)	(0.0294)
Control	FE	FE	FE	FE	FE	FE
AR (1)	1.71*	2.93***	3.27***			
AR (2)	−0.66	−0.04	−0.38			
Hansen	29.20	27.20	24.06			
F	1516.95	1751.36	1415.32	2303.43	2144.38	1920.91
Log-likelihood	895.2132	915.1158	855.1682	1023.4655	1021.4275	1013.6832
N	4794	4794	4794	4794	4794	4794
R^2				0.9809	0.9955	0.9771

$^*p < 0.1$, $^{**}p < 0.05$, $^{***}p < 0.01$.

Table 9
Mechanism regression results.

Variable	*IA*		*MS*	
	(1)	(2)	(3)	(4)
	IA	*Resmis*	*MI*	*Resmis*
η_{zr}	0.2386***	−0.7104***	−0.3381***	−0.5243***
	(0.0461)	(0.1336)	(0.1051)	(0.1339)
IA		−0.5873***		
		(0.1238)		
MS				0.1262**
				(0.0554)
Control	FE	FE	FE	FE
City-Year	FE	FE	FE	FE
N	4794	4794	4794	4794
R^2	0.8111	0.3008	0.1010	0.2778

$^*p < 0.1$, $^{**}p < 0.05$, $^{***}p < 0.01$.

sampling to ensure the robustness of the mechanism test. As seen in Table 10, the indirect effects of the mechanism variables are all significant and none of the confidence intervals contain zero, thus ensuring the robustness of the mechanism test. Therefore, hypothesis 2 and 3 is supported.

5.6. Heterogeneity analysis

Table 11 reports the results of the test for heterogeneity of city characteristics. In Columns (1) to (6), the regression coefficients of transportation infrastructure (η_{zr}) on resource misallocation are divided into values of −0.4827 and − 0.4441, both of which are significantly negative. In Columns (1) to (5), one can see that the mediating effects of IA and market integration in the eastern cities are 3.82 % (=0.2620 × 0.0704 / 0.4827)[2] and 5.93 % (=0.3428 × 0.0835 / 0.4827)④, respectively, and in terms of the magnitude of the effect values, the improvement of transportation infrastructure makes the eastern cities more dependent on market integration effects for resource allocation efficiency improvement. In Columns (6) to (10), one can see that the mediating effect of IA in the mid-western cities is 4.31 % (=0.1549 × 0.1237 / 0.4441)⑤, while the mechanism test of market integration is insignificant. Therefore, improved transportation infrastructure makes resource allocation efficiency improvement in eastern cities more dependent on market integration effects, whereas central and western cities rely more on IA effects.

Urban functional compactness mainly emphasizes highly dense development of population and buildings as well as mixed use of urban functions. Cities with different transportation bases may exhibit heterogeneity in their impact on regional resource allocation due to differences in urban functional compactness. Therefore, we examine the optimization of regional resource allocation under the perspective of urban compactness heterogeneity with reference to Harari (2020) using the Cohesion index as a measure of urban compactness and its median as a subgroup. Columns (11) and (12) show the regression results of the transportation base on regional resource allocation under the perspective of high and low urban compactness, respectively. It is found that the more compact the urban function, the better the driving effect of transportation base on the optimization of regional resource allocation.

6. Discussion

(1) Improvements in transportation infrastructure have a significant

[2] ④⑤Mediating effects (indirect effects) as a proportion of total effects=$\frac{\beta_0 \cdot \theta_1}{\alpha_0}$, α_0, β_0, θ_1 are located in model 19, 21, and 22, respectively.

Table 10
Bootstrap mediated effects test.

Variables	Effect	Observed Coef.	Bootstrap St. Err.	Sig	95 % Conf. Interval	
IA	Indirect effect	−0.1401***	0.0148	<0.0001	−0.0360	−0.0125
	Direct effect	−0.7104***	0.0905	<0.0001	−0.0414	−0.0298
MS	Indirect effect	−0.0427***	0.0052	<0.0001	−0.0075	−0.0014
	Direct effect	−0.5243***	0.0665	<0.0001	−0.0320	−0.0152

*$p < 0.1$, **$p < 0.05$, ***$p < 0.01$.

Table 11
Heterogeneity regression results.

Panel C: Heterogeneity Test I: East Cities					
Variable	*Resmis* (1)	*IA* (2)	*Resmis* (3)	*MS* (4)	*Resmis* (5)
η_{zr}	−0.4827* (0.2617)	0.2620*** (0.0569)	−0.4780* (0.2378)	−0.3428* (0.1968)	−0.4725* (0.2622)
IA			−0.0704* (0.0376)		
MS					0.0835* (0.0451)
Control	FE	FE	FE	FE	FE
City-year	FE	FE	FE	FE	FE
N	1785	1785	1785	1785	1785
R^2	0.6605	0.8258	0.6608	0.1638	0.6612
Panel D: Heterogeneity Test II: Midwest Cities					
Variable	*Resmis* (6)	*IA* (7)	*Resmis* (8)	*MS* (9)	*Resmis* (10)
η_{zr}	−0.4441*** (0.0420)	0.1549** (0.0659)	−0.4249*** (0.0760)	−0.0119 (0.1468)	−0.4098*** (0.0758)
IA			−0.1237* (0.0661)		
MS					0.0023 (0.0298)
Control	FE	FE	FE	FE	FE
City-year	FE	FE	FE	FE	FE
N	3009	3009	3009	3009	3009
R^2	0.2757	0.5918	0.2841	0.4151	0.2757
Panel E: Heterogeneity Test III: Urban Compactness					
Variable	*Resmis* (11)	*Resmis* (12)			
η_{zr}	−0.1926*** (0.0628)	−0.1159 (0.0825)			
Control	FE	FE			
City-year	FE	FE			
N	2397	2397			
R^2	0.1512	0.1227			

*$p < 0.1$, **$p < 0.05$, ***$p < 0.01$.

positive impact on regional resource allocation, with spatial spillover effects. Overall, transportation infrastructure is a key factor that affects regional economic development and resource allocation (Palmer, 2024). Improved transportation infrastructure can reduce transactions and time costs between regions, facilitating the free flow of resources and commodities (Dou et al., 2024; Li et al., 2018). When a city's transportation system is optimized, its enhanced external connectivity and internal mobility attract investment, promote employment, and accelerate the diffusion of technology and knowledge (Mao et al., 2024), promoting economic growth and spatial development in the region and neighboring areas (He et al., 2022; Palmer, 2024). Improvements in a region's transportation network significantly enhance the well-being of both residents and businesses, while also impacting spatially connected areas through network effects. The expansion and enhancement of transportation infrastructure stimulate additional economic activities within the network, thereby increasing the efficiency of resource allocation across the region. Consequently, enhanced transportation infrastructure in a city not only directly bolsters the local efficiency of resource distribution but also generates spatial spillover effects by lowering transaction costs with neighboring cities (Dou et al., 2024). This contributes to the overall efficiency of resource allocation within the region, aligning with the findings of Liu et al. (2024) and Mao et al. (2024).

Additionally, improved transportation infrastructure significantly increases the mobility of resource factors (e.g., labor, capital, information, and technology) between neighboring cities. This increased mobility not only reduces the cost and time associated with cross-regional transactions (Dou et al., 2024) but also facilitates the optimal allocation of resources across a broader regional scale in response to market demand and supply. This, in turn, maximizes resource utility and economic efficiency (Palmer, 2024). Thus, infrastructure enhancements serve as both a physical upgrade in connectivity and a catalyst for economic and technological collaboration, fostering balanced and sustainable economic growth while optimizing resource allocation within the region.

(2) Improved transportation infrastructure can increase the efficiency of regional resource allocation by inducing IA and alleviating MS. IAs have become centers of technological innovation and knowledge exchange (Long & Yi, 2024; Mao et al., 2024), and increased transportation infrastructure promotes interaction and cooperation among firms, accelerates the diffusion of technology and knowledge, and promotes the overall innovation and progress of industry (He et al., 2022; Mao et al., 2024). IAs can be used as engines of regional development. Different regions can develop into experts in a particular industry or technology field through the agglomeration effect, thereby forming

regional characteristics and competitive advantages. This specialized and differentiated development model helps regions form complementarities in resources and technologies, promoting synergistic development and economic diversity (Palmer, 2024; Wang & Wang, 2024). Additionally, regions with convenient transportation are more likely to attract high-quality talent and specialized labor. IA also promotes the specialized division of labor, enabling each enterprise or region to focus on its comparative advantages and improve its overall productivity and competitiveness.

With improvements in transportation networks, MS, which was previously caused by transportation constraints, has been significantly reduced. Improved transportation infrastructure facilitates economic linkages between regions, reduces geographical and temporal barriers, and allows regional markets to become more closely connected (Palmer, 2024). Such connectivity enhances market integration and creates conditions for the free flow of goods and services across a wider region, thereby enabling goods and services to reach the areas of greatest demand more smoothly and maximizing market efficiency (Meng et al., 2024). Furthermore, increased transportation infrastructure allows resources to be efficiently allocated across a wider region according to market demand and supply conditions (Barwick et al., 2021). Additionally, improved market conditions greatly increase information mobility, facilitating the rapid dissemination and sharing of market information (Long & Yi, 2024). Such information flows have improved market transparency, providing market participants with a more accurate picture of the supply, demand, and price levels in different regions (Long & Yi, 2024). Improving price consistency is crucial for the effective operation of the market, as it helps ensure that resources are efficiently and rationally allocated and used over a wider range.

(3) Heterogeneity analysis revealed that improved transportation infrastructure improves resource allocation efficiency in eastern cities, which are more dependent on market integration effects, whereas central and western cities rely more on IA effects. This finding can be explained as follows. First, increased transportation infrastructure can connect different economic entities more effectively, strengthening the network effect and improving the efficiency of resource allocation (Glaeser, 2000). This effect is less pronounced in central and western cities with relatively decentralized economies that lack strong industrial and commercial bases. Second, eastern cities typically have more convenient access to domestic and international markets because of their favorable geographic locations (Meng et al., 2024). Improved transportation infrastructure, especially ports and logistics, can greatly facilitate trade and market expansion, and further improve the efficiency of resource allocation. Comparatively, as a result of geographic constraints, it is difficult for cities in the central and western regions to capitalize on this advantage to the same extent, even if transportation infrastructure is improved (Holl, 2007). Finally, considering the marginal effect of infrastructure investment, eastern cities already have a more mature transportation infrastructure. In this case, further investments and improvements typically result in higher marginal benefits because they are based on an already highly developed and integrated network. In contrast, cities in the central and western regions of the country may require more initial investment to achieve similar benefits.

In eastern cities, where economies are already highly developed and markets are mature, improvements in transportation infrastructure work primarily through the integration of existing markets. Considering the diverse needs of mature markets in eastern cities, a rapid response to changes in market demand and consumer preferences has a greater impact on resource allocation efficiency (Wang et al., 2024). Therefore, the optimization effect of improved transportation infrastructure on IA is marginally diminishing, and its influence is not as obvious as the effect of market integration. Excessive IA may lead to overconcentration of resources and reduced efficiency. Therefore, market integration has become a more important driving force in the eastern region.

The economies of cities in the central and western regions are largely dominated by specific industries that are mainly concentrated in specific areas, forming clear IAs. In this context, improved transportation infrastructure mainly facilitates the flow of resources and efficiency within agglomeration areas by improving the transportation of raw materials, facilitating the expansion of product markets, and enhancing technological exchange. Compared with eastern cities, central and western cities have smaller markets, more homogenous market structures, and less mature market mechanisms, limiting the role of market integration effects in resource allocation. Additionally, the traditionally relatively poor transportation infrastructure and regional connectivity of cities in the mid-western region have led to recent improvements in transportation infrastructure, focusing on strengthening internal connectivity, especially internal transportation networks in IA areas.

In addition, the optimization of regional resource allocation by the transport base shows heterogeneity in terms of urban compactness. One of the characteristics of compact cities is a high-density land development and use pattern, and from a geometric point of view, other things being equal, spatially morphologically compact cities are characterized by a reduction in the distance between points within the city (Hamidi & Ewing, 2014). Based on the geometrically efficient nature of compact cities, cities that are less compact need to build a greater amount of transportation infrastructure for the same level of spatial accessibility to transportation, all other things being equal. Therefore, the optimization of resource allocation by transport infrastructure is better in highly compact cities.

(4) The methodology developed and applied in this study aims to analyze the impact of transportation infrastructure on the efficiency of regional resource allocation and has broad applicability and scalability. First, this methodology can be used in urban planning and development to gain a deeper understanding of how improvements in transportation infrastructure affect resource allocation within cities, thereby providing data support for infrastructure investment decisions and urban development strategies (Hermelin & Henriksson, 2022).

Second, policymakers involved in regional economic integration can use this method to evaluate the effects of transportation projects on regional economic integration, which is particularly important in developing countries with significant regional disparities (Mao et al., 2024). Additionally, the supply chain and logistics management sector can utilize our research results to optimize supply chains and analyze the impact of transportation infrastructure improvements on cost reduction and efficiency (Dou et al., 2024). Environmental and sustainability researchers can employ our method to assess the impact of transportation infrastructure on environmental sustainability and resource use efficiency, allowing them to formulate more sustainable transportation policies (Palmer, 2024). This study proposed a theoretical framework that can be used by government departments to design and implement policies that optimize resource allocation through improved transportation infrastructure and promote inclusive economic growth. Our method can be used by international development aid agencies to evaluate the impacts of infrastructure development projects, particularly the role of international aid funds in regional economic development.

Finally, our methodology can enhance the healthcare and emergency services sector by analyzing the impact of transportation infrastructure on the efficiency of medical resources allocation. By adjusting and applying the methodology developed in this study, stakeholders in different fields can explore the multifaceted impacts of transportation infrastructure on resource allocation and regional development, further highlighting the broader academic significance and practical value of our research findings beyond the specific context of China.

Different countries exhibit variations in transportation infrastructure construction due to differences in policies, economies, and cultures. By adopting our methodology, these countries can assess and optimize resource allocation efficiency within their respective institutional contexts. For instance, in developed countries, this method can assist policymakers in enhancing existing transportation networks to address the complex challenges posed by urbanization. Conversely, in developing countries, this framework can provide critical data support for infrastructure investments, thereby fostering regional economic integration and sustainable development. Moreover, international organizations and development aid agencies can utilize this methodology to evaluate and compare the effectiveness of transportation infrastructure projects across diverse national and regional settings, enabling the formulation of more targeted and effective policies. The application of our methodological framework across various global institutional contexts can enhance international cooperation and knowledge exchange in the domain of transportation infrastructure development and resource optimization, ultimately promoting coordinated global economic growth.

7. Conclusions and policy implications

7.1. Conclusions

Accelerating the establishment of China's unified large market and opening up key blockages that constrain its economic cycle are inherent requirements for China to promote high-quality economic development going forward. Based on city-level data from 2005 to 2021, we empirically investigated the micro-impact of transportation infrastructure on regional resource allocation efficiency and its mechanisms in the context of China's unified large market. We explored how the improvement of transportation infrastructure promotes the cross-regional mobility of production factors and improves overall operational efficiency. The main conclusions of this study can be summarized as follows:

First, improvements in transportation infrastructure contribute to the improvement of intra-regional resource allocation efficiency and can generate positive spatial spillover effects on neighboring regions.

Second, our mechanism analysis revealed that improved transportation infrastructure can improve regional resource allocation efficiency by inducing IA and alleviating MS.

Third, heterogeneity analysis demonstrated that improved transportation infrastructure makes the resource allocation efficiency of eastern cities more dependent on market integration effects, whereas central and western cities rely more on IA effects. Meanwhile, transportation infrastructure optimizes resource allocation better in highly compact cities.

7.2. Policy implications

First, governments should enhance the comprehensive layout of various transportation modes, including highways, railroads, airways, and water transport. Such comprehensive planning can ensure the seamless connection of transportation networks within and outside different regions, providing a solid foundation for IA and resource flows. Additionally, establishing an intra-regional transportation information sharing and technology exchange platform is crucial for enhancing the overall efficiency of resource allocation. This approach promotes information sharing and technical cooperation between regions, thereby improving the efficiency and accuracy of decision making to meet regional development needs. At the local level, this strategy can improve urban and regional transportation flows and economic activity. On an international scale, these platforms facilitate global cooperation and encourage the exchange of advancements in transportation technologies, policies, and infrastructure management. This, in turn, supports global trade, reduces transit time, enhances supply chain efficiency, and fosters economic cooperation and growth.

Second, governments should focus on removing administrative and legal barriers that lead to MS. Specific measures include simplifying administrative procedures for cross-regional transactions, harmonizing regulations and policies between regions, and reducing unnecessary local protectionism to ensure a unified nationwide market environment. Governments should develop and implement nationally harmonized technical standards, quality norms, and trading rules while reducing the compliance costs faced by enterprises operating in different regions. The key to enhancing trade efficiency is through trade facilitation, simplifying tariff procedures, improving customs efficiency, and optimizing logistics and transport infrastructure. Eliminating regional differences in the investment climate would help attract more investment and facilitate the efficient allocation and flow of capital within the national market by integrating capital markets. Internationally, these measures can foster global cooperation, streamline cross-border transactions, and enhance global trade efficiency by aligning regulatory standards and optimizing global logistics, thereby supporting economic growth and integration on a global scale.

Finally, governments in different administrative regions must collaborate to develop and adhere to regional transportation planning frameworks. Such frameworks should cover long-term goals, priorities, and key projects for the development of transportation networks that require a consensus among regional governments. Furthermore, establishing a cross-regional cooperation mechanism is essential for achieving continuity in transportation networks. This can be accomplished by forming regional transportation management committees or coordination groups consisting of representatives from regional governments, transportation experts, and stakeholders to oversee the implementation of regional transportation plans, resolve coordination issues, and adjust policies as needed. At the local level, this approach ensures that transportation projects are strategically planned and executed, promoting regional development and promptly addressing issues. For example, within a country, these frameworks can align regional development efforts and ensure efficient resource allocation. At the international level, these frameworks can harmonize cross-border transportation initiatives, enhance global cooperation, streamline regulatory procedures, and promote the sharing of best practices and technological innovations. International collaboration can facilitate global trade, reduce transit times, improve supply chain efficiency, and support economic growth and sustainable development across regions and countries. By implementing these policy recommendations, local and international entities can enhance the efficiency and integration of transportation networks, foster economic growth, improve resource allocation, and ensure sustainable development.

8. Research gaps and outlook

This study only focused on the internal mechanisms of transportation infrastructure improvement on regional resource allocation efficiency from the perspective of IA and market integration and did not identify or exclude other possible transmission mechanisms, such as the technological innovation effect brought about by transportation infrastructure improvement. Additionally, when searching for related literature, we found that the latest studies on the measurement of transportation infrastructure could be expanded by constructing models using ARCGIS, but the resulting workload would be more cumbersome. Therefore, most studies only focus on a single city. In the future, we will consider how to simplify the process of constructing transportation networks using ARCGIS to provide a more detailed portrayal of China's transportation infrastructure index, which provides room for continuous exploration in subsequent research.

CRediT authorship contribution statement

Changshuai Cao: Writing – original draft, Software, Resources, Funding acquisition, Formal analysis, Data curation. **Yingjuan Su:** Writing – review & editing, Visualization, Project administration, Investigation.

Declaration of competing interest

The authors do not have any possible conflicts of interest.

Data availability

Data will be made available on request.

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References

Albacete, X., Olaru, D., Paül, V., & Biermann, S. (2017). Measuring the accessibility of public transport: A critical comparison between methods in Helsinki. *Applied Spatial Analysis and Policy, 10*, 161–188.

Aoki, S. (2012). A simple accounting framework for the effect of resource misallocation on aggre- gate productivity. *Journal of the Japanese and International Economies, 26*(4), 473–494.

Ashworth, G. J., & Goodall, B. (Eds.). (1990). *Marketing tourism places* (p. 140). Routledge.

Asturias, J., Santana, M. G., & Ramos, R. (2014). Misallocation, internal trade, and the role of transportation infrastructure. *CEMFI (Centro de Estudios Monetarios y Financieros).*

Banerjee, A., Duflo, E., & Qian, N. (2020). On the road: Access to transportation infrastructure and economic growth in China. *Journal of Development Economics, 145*, Article 102442.

Banerjee, A. V., & Moll, B. (2010). Why does misallocation persist? *American Economic Journal: Macroeconomics, 2*(1), 189–206.

Barwick, P. J., Cao, S., & Li, S. (2021). Local protectionism, market structure, and social welfare: China's automobile market. *American Economic Journal: Economic Policy, 13*(4), 112–151.

Barzin, S., D'Costa, S., & Graham, D. J. (2018). A pseudo–panel approach to estimating dynamic effects of road infrastructure on firm performance in a developing country context. *Regional Science and Urban Economics, 70*, 20–34.

Baum-Snow, N., Brandt, L., Henderson, J. V., Turner, M. A., & Zhang, Q. (2017). Roads, railroads, and decentralization of Chinese cities. *Review of Economics and Statistics, 99*(3), 435–448.

Brandt, L., Tombe, T., & Zhu, X. (2013). Factor market distortions across time, space and sectors in China. *Review of Economic Dynamics, 16*(1), 39–58.

Chacon-Hurtado, D., Kumar, I., Gkritza, K., Fricker, J. D., & Beaulieu, L. J. (2020). The role of transportation accessibility in regional economic resilience. *Journal of Transport Geography, 84*, Article 102695.

Collard-Wexler, A., & De Loecker, J. (2015). Reallocation and technology: Evidence from the US steel industry. *American Economic Review, 105*(1), 131–171.

Dalvi, M. Q., & Martin, K. M. (1976). The measurement of accessibility: Some preliminary results. *Transportation, 5*(1), 17–42.

Diao, M. (2018). Does growth follow the rail? The potential impact of high-speed rail on the economic geography of China. *Transportation Research Part A: Policy and Practice, 113*, 279–290.

Donaldson, D. (2018). Railroads of the raj: Estimating the impact of transportation infrastructure. *American Economic Review, 108*(4–5), 899–934.

Dou, H., Pang, X., Ke, H., & Liu, Y. (2024). Pain or gain? The effects of transportation infras- tructure on labor costs in China 1. *International Review of Economics & Finance, 91*, 413–431.

Fan, C. C., & Scott, A. J. (2003). Industrial agglomeration and development: A survey of spatial economic issues in East Asia and a statistical analysis of Chinese regions. *Economic Geography, 79*(3), 295–319.

Geertman, S. C., & Ritsema Van Eck, J. R. (1995). GIS and models of accessibility potential: An application in planning. *International Journal of Geographical Information Systems, 9*(1), 67–80.

Glaeser, E. L. (2000). The new economics of urban and regional growth. *The Oxford Handbook of Economic Geography, 37*(3), 289–302.

Guo, K., Hang, J., & Yan, S. (2021). Servicification of investment and structural transformation: The case of China. *China Economic Review, 67*, Article 101621.

Hagerstrand, T. (1974). Impact of transport on the quality of life. Proceeding of the 5th Interna- tional symposium on theory and practice in transport economics, transport in the 1980–1990 decade. *Athens, 1*(5).

Hamidi, S., & Ewing, R. (2014). A longitudinal study of changes in urban sprawl between 2000 and 2010 in the United States. *Landscape and Urban Planning, 128*, 72–82.

Harari, M. (2020). Cities in bad shape: Urban geometry in India. *American Economic Review, 110*(8), 2377–2421.

Harris, C. D. (1954). The, market as a factor in the localization of industry in the United States. *Annals of the Association of American Geographers, 44*(4), 315–348.

He, Q., Yan, M., Zheng, L., & Wang, B. (2023). Spatial stratified heterogeneity and driving mechanism of urban development level in China under different urban growth patterns with optimal parameter-based geographic detector model mining. *Computers, Environment and Urban Systems, 105*, Article 102023.

He, Z. X., Cao, C. S., & Wang, J. M. (2022). Spatial impact of industrial agglomeration and environmental regulation on environmental pollution—Evidence from pollution-intensive industries in China. *Applied Spatial Analysis and Policy, 15*(4), 1525–1555.

Hermelin, B., & Henriksson, M. (2022). Transport and mobility planning for sustainable develop- ment. *Planning Practice & Research, 37*(5), 527–531.

Holl, A. (2007). Twenty years of accessibility improvements. The case of the Spanish motorway building programme. *Journal of Transport Geography, 15*(4), 286–297.

Holl, A. (2016). Highways and productivity in manufacturing firms. *Journal of Urban Economics, 93*, 131–151.

Hsieh, C. T., & Klenow, P. J. (2009). Misallocation and manufacturing TFP in China and India. *The Quarterly Journal of Economics, 124*(4), 1403–1448.

Kander, A. (2005). Baumol's disease and dematerialization of the economy. *Ecological Economics, 55*(1), 119–130.

Li, H., Strauss, J., Shunxiang, H., & Lui, L. (2018). Do high-speed railways lead to urban economic growth in China? A panel data study of China's cities. *The Quarterly Review of Economics and Finance, 69*, 70–89.

Linneker, B. J., & Spence, N. A. (1992). An accessibility analysis of the impact of the M25 London orbital motorway on Britain. *Regional Studies, 26*(1), 31–47.

Liu, Y., Tang, D., & Wang, F. (2024). Research on the spatial spillover effect of high-speed railway on the income of urban residents in China. *Humanities and Social Sciences Communi- cations, 11*(1), 1–13.

Long, C. X., & Yi, W. (2024). Information effects of high-speed rail: Evidence from patent citations in China. *China Economic Review, 84*, Article 102115.

Lösch, A. (1938). The nature of economic regions. *Southern Economic Journal*, 71–78.

Majewska, J. (2015). Inter-regional agglomeration effects in tourism in Poland. *Tourism Geographies, 17*(3), 408–436.

Mao, N., Sun, W., & Zhang, L. (2024). The innovation effects of transportation infrastructure: Evidence from highways in China. *Economics of Transportation, 38*, Article 100352.

Melitz, M. J. (2003). The impact of trade on intra-industry reallocations and aggregate industry productivity. *Econometrica, 71*(6), 1695–1725.

Melitz, M. J., & Polanec, S. (2015). Dynamic Olley-Pakes productivity decomposition with entry and exit. *The Rand Journal of Economics, 46*(2), 362–375.

Meng, X., Li, J., Zhou, X., & Yao, X. (2024). Transportation infrastructure, market access, and firms' export competition: Evidence from China. *Finance Research Letters, 61*, Article 105022.

Moseley, M. J. (1979). *Accessibility: The rural challenge* (1st ed.). Routledge.

Palmer, E. (2024). Roads and rules: What does infrastructure reveal about international law? *Asian Journal of International Law, 14*(1), 180–207.

Parsley, D. C., & Wei, S. J. (2001). Explaining the border effect: The role of exchange rate varia- bility, shipping costs, and geography. *Journal of International Economics, 55*(1), 87–105.

Qin, Y. (2017). "No county left behind?" the distributional impact of high-speed rail upgrades in China. *Journal of Economic Geography, 17*(3), 489–520.

Redding, S. J., & Sturm, D. M. (2008). The costs of remoteness: Evidence from German division and reunification. *American Economic Review, 98*(5), 1766–1797.

Restuccia, D., & Rogerson, R. (2013). Misallocation and productivity. *Review of Economic Dynamics, 16*(1), 1–10.

Rivera, L., Sheffi, Y., & Welsch, R. (2014). Logistics agglomeration in the US. *Transportation Research Part A: Policy and Practice, 59*, 222–238.

Shen, Q. (1998). Spatial technologies, accessibility, and the social construction of urban space. *Computers, Environment and Urban Systems, 22*(5), 447–464.

Song, Z., Storesletten, K., & Zilibotti, F. (2011). Growing like China. *American Economic Review, 101*(1), 196–233.

Tao, X., Xiong, B., & An, Q. (2021). DEA-based centralized resource allocation with network flows. *International Transactions in Operational Research, 28*(2), 926–958.

Vickerman, R. W. (1974). Accessibility, attraction, and potential: A review of some concepts and their use in determining mobility. *Environment and Planning A, 6*(6), 675–691.

Wang, C., & Wang, L. (2024). Does broadband infrastructure promote urban innovation? Evidence from "broadband China" demonstration policy. *Structural Change and Economic Dynamics, 69*, 349–362.

Wang, S., Zhao, D., & Chen, H. (2020). Government corruption, resource misallocation, and ecological efficiency. *Energy Economics, 85*, Article 104573.

Wang, Y., Sun, B., Zhang, T., & Yu, M. (2024). Can polycentric cities provide more and higher-order consumer amenities? Evidence from shopping malls in China. *Applied Geography, 164*, Article 103198.

Wei, Q., Zhang, J., & Zhang, X. (2000). An inverse DEA model for inputs/outputs estimate. *European Journal of Operational Research, 121*(1), 151–163.

Weibull, J. W. (1976). An axiomatic approach to the measurement of accessibility. *Regional Science and Urban Economics, 6*(4), 357–379.

Young, A. (2000). The razor's edge: Distortions and incremental reform in the People's Republic of China. *The Quarterly Journal of Economics, 115*(4), 1091–1135.

Yu, P., Chen, Y., Xu, Q., Zhang, S., Yung, E. H. K., & Chan, E. H. W. (2022). Embedding of spatial equity in a rapidly urbanising area: Walkability and air pollution exposure. *Cities, 131*, Article 103942.
Yu, P., Zhang, S., Yung, E. H., Chan, E. H., Luan, B., & Chen, Y. (2023). On the urban compact- ness to ecosystem services in a rapidly urbanising metropolitan area: Highlighting scale effects and spatial non–stationary. *Environmental Impact Assessment Review, 98*, Article 106975.
Zheng, S., & Kahn, M. E. (2013). China's bullet trains facilitate market integration and mitigate the cost of megacity growth. *Proceedings of the National Academy of Sciences, 110*(14), E1248–E1253.

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