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ORIGINAL PAPER

Quantifying economic effects of transportation investment considering spatiotemporal heterogeneity in China: a spatial panel data model perspective

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Abstract
Transportation investment plays a significant role in promoting economic development. However, in what scenario and to what extent transportation investment can stimulate economic growth still remains debatable. For developing countries undergoing rapid urbanization, answering these questions is necessary for evaluating proposals and determining investment plans, especially considering the heterogeneity of spatiotemporal conditions. Current literature lacks systematical research to consider the impacts of panel data and spatial correlation issue in examining the economic effects of transportation investment. To fill this gap, this study collects provincial panel data in China from 1997 to 2015 to evaluate multi-level temporal and spatial effects of transportation investment on economic growth by using spatial panel data analysis. Results show that transportation investment leads to significant and positive effects on growth and spatial concentration of economic activities, but these results vary significantly depending on the temporal and spatial characteristics of each province. The economic impacts of transportation investment are quite positive even considering the time lag effects. This study suggests that both central and local governments should carefully evaluate the multifaceted economic effects of transportation investment, such as a balanced transportation investment and economic development between growing and lagging regions, and considering the spatiotemporal heterogeneity of the economic environment.

JEL Classification C33 · R40 · R58

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1 Introduction

Transportation investment is a key factor in promoting economic growth and regional integration. In most developing countries and regions, transportation infrastructure investment has been planned to enhance economic vitality. The question of how to make the most effective use of transportation investment in the promotion of economic growth has become a crucial item on the planning agenda of urban and metropolitan planning regions. The transportation studies and economic geography literature reveals the close interaction between transportation investment and economic performance (Wetwitoo and Kato 2017; Kim et al. 2017; Diao 2018; Sun and Cui 2018). For example, changes in accessibility and transportation cost can affect the magnitude and regional distribution of the benefits provided by economic activity (Alonso 1964; Aschauer 1990; Fujita et al. 1999; Holmgren and Merkel 2017; Jia et al. 2017).

Though the economic effects of transportation investment have been examined at some length (Achour and Belloumi 2016; Chen and Vickerman 2017), the impact of transportation investment on economic growth is still a matter of debate. The economic benefits conferred by transportation investment depend on local socioeconomic conditions and are sensitive to methodological issues. For instance, the net benefits associated with transportation investment depend on economic potential and geographic variation, and the most substantial benefits are likely when transportation investments are motivated to bridge a regional accessibility gap or to alleviate economic disparity (Chen and Haynes 2017). However, the economic impacts of transportation investment may prove illusory (Melo et al. 2013; Shi et al. 2017) or unclear due to a variety of contextual or methodological issues in different regions (Deng 2013).

Thus a better understanding of the effectiveness of transportation investment under various constraints is still much needed. On the one hand, it usually takes several years to construct and operate transportation infrastructure before the improved transportation system generates measurable impacts on regional economies. On the other hand, the economic effects of transportation investment could be subject to different geographic and socioeconomic conditions. In China, for example, regional development is unbalanced and highly regionalized (Diao 2018). Eastern China has an excellent record of economic development and transportation benefits from substantial investment in multimodal services. However, China's central and western regions are progressing much more slowly and from a lower base with many out-migrants moving to the large coastal cities of Eastern China. Due to potential externalities, the spillover effects of transportation investments may be substantial as investment benefits in one region spread to neighboring regions. Démurger (2001) argued that "as a key differentiating factor," transportation infrastructure has expanded China's inter-regional growth gap: narrowing the urban and rural disparity in Eastern China while enlarging it in Central and Western China.

To capture these regional spillovers, transportation investment–economic development research needs to consider the joint impacts of panel data and spatial correlation. Recent spatial panel data model (SPDM) development provides a new opportunity to re-assess the regional economic impacts of transportation infrastructure investment (Belotti et al. 2016). This opportunity is especially relevant at this time because massive investment in transportation infrastructure is anticipated under China's 13th and 14th Five-year Plan ending in 2025.

This paper will employ several spatial panel data models to examine the multi-level temporal–spatial effects of provincial-level transportation investment in China from 1997 to 2015. By doing so, this paper addresses three important issues. Will the unprecedented scale of transportation investment in China reach its potential to promote economic growth? Second, since the geographically based analysis cannot avoid the challenge posed by spatial autocorrelation (Meng et al. 2018), how would the relationship between transportation investment and economic development change if the effects of spatiotemporal heterogeneity could be incorporated? Third, what are the implications of the above findings for the promotion of economic growth through transportation investment? The answers to these questions will show the multi-level effects of transportation investment on economic growth and provide economic development policy insights for China and beyond.

2 Literature review

2.1 General effects of transportation investment

Transportation cost and accessibility are important factors affecting location choices. Transportation investment and the improved accessibility may attract additional investment (e.g., foreign direct investment or induced investment) as well as promote employment growth, regional specialization, and inter-regional trade by lowering transportation costs (Ansar et al. 2016; Knowles and Ferbrache 2016; Chakrabarti 2018). The new economic geography (NEG) focuses on how reduced transportation costs can foster inter-regional flows of labor and promote scale and agglomeration effects (Fujita et al. 1999; Berechman et al. 2006; Holmgren and Merkel 2017). The decrease in transportation costs and the application of new transportation technology can promote the efficiency and spatial agglomeration of economic activities (Tokunova 2018). The shift in transportation costs can affect the locational choices of both employers and the labor force (Sharif et al. 2019). Such investments may also lead to significant changes that promote economic growth over the short- and long-run (Maparu and Mazumder 2017; Rothengatter 2017). In summary, a significant improvement in transportation infrastructure and inter-regional connectivity can reduce time and monetary costs for enterprises and shift their optimal locations and spatial distributions, resulting in scale and agglomeration effects on the level of production efficiency (Nocke 2006; Beyzatlar et al. 2014).

The impact of transportation investment on economic growth and regional cohesion is generally contingent on the location, population density, and spatial structure of the region receiving the investment (Stepniak and Rosik 2013). For example, Berechman et al. (2006) observed that transportation investment has an insignificant economic impact at the state level, but a significant positive impact at the county level. Canning and Fay (1993) estimated the marginal productivity of transportation capital using a panel regression model of 96 counties and found that transportation investment has greater economic effects in industrializing countries than in underdeveloped countries. Melo et al. (2013) concluded that the benefits of transportation infrastructure differ across different industries and the effects in the USA are higher than in several European countries. Regions at a higher level in the transportation system hierarchy can generate significant economic impacts in neighboring regions. In contrast, highway investment in China at the provincial level can help reduce the "Gini coefficient of per capita mileage of high-grade highway" (Chen et al. 2016). However, transportation investment may have a negative correlation with economic growth in less developed regions (Jiang et al. 2016). These differences reflect the importance of the economic efficiency of transportation investment at the regional scale (Andrejić et al. 2016).

2.2 Spatiotemporal heterogeneity in revealing transportation investment—economic growth connections

One of the unique features of transportation investment is its spillover effect in neighboring regions (Eberts 1990). For example, Pereira and Roca-Sagales (2003) found that the concentration effects of public capital invested in Spanish regions include both direct and spillover effects. The life cycle of transportation investment, such as time required for design, construction, and operation, imposes a significant time lag before the spillovers take effect and the increased productivity or economic growth are detected. Ozbay et al. (2007) compared the different spillover effects of highway investment in the New York metropolitan area and found that these effects are reinforced as time progresses. Similarly, by using input and output analysis, Zong and Wu (2011) pointed out that the elasticity of transportation investment in Beijing to economic growth is 2–3%, but the impacts experience a decline in the long term. The economic effects of transportation investment are modally dependent. Due to its high level of travel flexibility and wide range of services, road transportation investment has much higher spillover effects than rail or marine shipment modes (Melo et al. 2013).

The disparity in productivity benefits and economic returns is largely caused by geographic spillovers (Holtz-Eakin and Schwartz 1995). According to the meta-analysis, the current methodology to estimating transportation investment's economic impacts includes the growth regression, production function, spatial regression, generalized method of moments, vector auto-regression, total factor productivity (Melo et al. 2013; Deng 2013; Elburz et al. 2017; Holmgren and Merkel 2017). Different data and methodologies can account for different outcomes and sources of variation. For instance, Elburz et al. (2017) found that "infrastructure type, study methodology, span of time, and geographical scale" are the most influential factors in the connection between transportation investment and economic growth.

2.3 The use of spatial panel data model in addressing spatiotemporal heterogeneity

Since the spatiotemporal-related effects of transportation investment cannot be effectively captured, it is necessary to adopt effective measurement models to address the spatiotemporal heterogeneity phenomenon. However, spatial regression models have attracted relatively little attention. For example, in the meta-analysis conducted by Elburz et al. (2017), only 49 of 751 observations use spatial regression models to investigate and estimate the impacts of transportation investment. More recently, the development of SPDM provides a new technique to re-assess the connection between transportation investment and economic growth by considering spatiotemporal heterogeneity. SPDM can be applied to panel data with both individual and time effects and it can incorporate spatial autocorrelation by introducing a spatial weight matrix (SWM). In addition to spatiotemporal heterogeneity, the endogeneity problem should also be addressed. For instance, investment in transportation can promote economic growth while transportation investment is often induced by economic development. Hence, there is an endogeneity problem: is transport investment a cause or an effect of economic growth? To address such problems, more effective instrument variables (IVs) are required in econometric models.

Though several studies have already used spatial econometric techniques to assess the economic impacts of transportation investment (Zhang 2008; Yu et al. 2013), more refined models to deal with both spatiotemporal heterogeneity and endogeneity problems are still much needed. For instance, several studies have applied spatial econometric techniques to evaluate the economic effects of transportation investment but failed to cope effectively with the problem of endogeneity (Zhang 2008). In this paper, several instrument variables, such as the average elevation (ELE) of each province and the q-statistic measure, will be employed in the SPDM to simultaneously capture the spatial–temporal effects of transportation investment and deal with the endogeneity problem. Note that transportation investment can affect the city or regional economic growth through a variety of different relationships between variables. The spatial panel data model may not calculate all of the possible ways that transportation investment may be affected. In such cases, a structural equation model would have certain advantages to detect and measure the multiple causal pathways that transportation investment may follow to affect economic growth (Jiang et al. 2017). However, the objective of this study is to cope with the problems of spatial autocorrelation and endogeneity under the same SPDM framework. Thus we have chosen not to apply structural equation models to understand the multi-dimensional economic effects of transportation investment.

3 Study area and research design

3.1 Transportation investment in China

After the adoption of the opening-up policy in 1978 and progressive economic reforms in China since that time, economic performance has experienced rapid

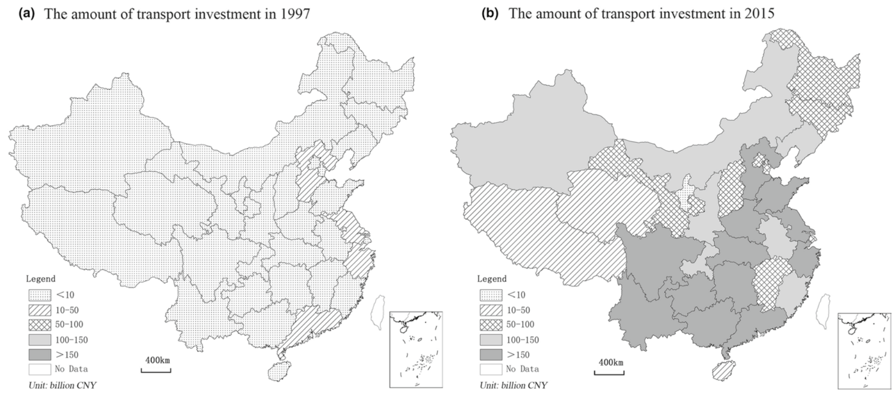

Fig. 1 Transportation investment in China by province, 1997 and 2015

growth, especially at the city and regional scale. Gross domestic product (GDP) reached ¥90.03 trillion while urbanization climbed to 59.58% in 2018, a big leap compared to ¥365 billion and 20% in 1978, respectively. Keeping pace with this economic growth trend, transportation investment increased from ¥8 million in 1978 to ¥3264 billion in 2014 in a comprehensive transportation system, including railways, highways, high-speed rail lines, and urban transit systems, to improve the connections within and between urban regions. According to China's 13th Five-Year National Strategic Plan, the total investment in transportation will rise to ¥15 trillion in 2020, adding 30 thousand highway kilometers and 320 thousand kilometers to the total length of the nation's railway network (Ministry of Transport of China 2017).

The total amount of transportation investment in China has grown enormously yet with profound regional differences. Figure 1 shows the annual transportation investment in 31 provinces of China in 1997 and 2015. The most noteworthy trend is that the capital expenditures in transportation are closely linked to national economic growth. For example, in 1997, the total transportation investment in China was ¥172.2 billion, an average of ¥5.1 billion per province. By 2005, the national transportation investment reached ¥866.9 billion, four times higher than in 1997. The average provincial investment in 2005 was ¥25.5 billion, while in 2015, the national total transportation investment and provincial average reached ¥4466.3 billion and ¥144.1 billion, respectively.

However, transportation investment in China has followed a regionally targeted financial pattern in which key areas receive the highest funding priorities from the central and provincial governments. The level of transportation services and transportation efficiency is unevenly distributed. For example, from eastern to western China, transportation efficiency shows a descending trend, and the efficiency in most provinces is not as high as expected based on system-wide averages (Li et al. 2016).

Transportation investment in 1997 was concentrated in just the four most highly developed provinces: Guangdong, Jiangsu, Hebei, and Zhejiang, accounting for 31.48% of the national total. Qinghai and Tibet had the lowest investment intensity (about ¥0.7 billion), less than one percent of the national total in 1997. By 2005, the

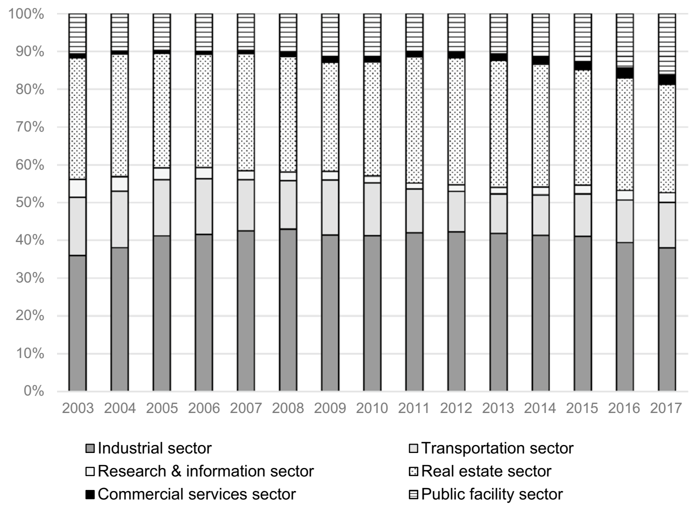

Fig. 2 Investment in fixed assets by major economic sector in China. *Source*: National Bureau of Statistics of China, http://www.stats.gov.cn/tjsj/ndsj/

regional distribution of transportation investment was more evenly dispersed with Zhejiang, Guangdong, Jiangsu, and Henan, receiving about 28.67% of the national total. Investment in the transportation system became even more diffuse in 2015 with the top four provinces: Guangdong, Sichuan, Hebei, and Shandong, accounting for only 25.36% of the total. The lowest transportation investment was in Ningxia (about ¥15.42 billion), which only accounts for 0.58% of the national total.

Transportation investment has expanded rapidly since the 1990s. However, the proportion of transportation investment in fixed assets was considerably less than the real estate and industrial sectors while its growth rate was comparatively stable (Fig. 2).

3.2 Research framework

To fill the current research gap, the objective of this study is to construct SPDM to estimate the multi-level economic impacts of transportation investment in China while controlling for spatial autocorrelation (Fig. 3). These models are based on three hypotheses concerning large-scale transportation infrastructure investment in China: (1) Transportation investment in China at the provincial level can generate significant and positive effects on economic growth; (2) the economic effects of transportation investment will decrease when spatiotemporal heterogeneity is incorporated by introducing spatial panel data; (3) there is significant variance in the economic effects of transportation investment in different subregions and periods. To test these hypotheses, the results of SPDM, as well as the pooled ordinary least squares (OLS) and panel regression models, will be provided and compared. To cope with endogeneity problems, this research will apply the *q*-statistic (Wang et al. 2016) and average elevation which represent the heterogeneity of economic

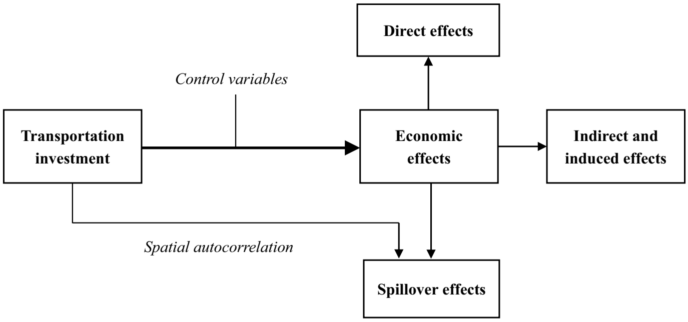

Fig. 3 Research framework of this study

development and physical geography conditions, respectively. In this way, the study can provide reliable implications for evaluating transportation investment proposals.

3.3 Data and variables

Based on similar indicators employed elsewhere (Yu et al. 2012; Chen and Vickerman 2017; Vickerman 2018), we assume the gross domestic product (ECON) in region i in year j is largely influenced by regional transportation investment (RTI), regional non-transportation investment (RNTI), regional size of the labor force (RLAB), and regional level of urbanization (RURBAN). Indeed, the economic transformations largely benefit from the sustained support from the skilled and low-cost labor force (Kim and Kim 2015). We calculate these variables as the sum of the annual amounts in each year. Considering the significant locational differences among China's provinces, some studies use dummy variables to investigate whether and how a single unit's location in the Eastern or Middle China would affect its economic growth potential. However, this may not reveal the impact of spatial differences in productivity. In order to overcome this deficiency, we introduce the spatially stratified heterogeneity q-statistic based on provincial GDP per capita to measure China's regional disparities (Wang et al. 2016).

To reduce the issue of heterogeneity and endogenous impacts, we introduced another control variable to incorporate the average elevation (ELE) of each province into the empirical models, which is calculated in "ArcGIS 10.0" based on China's Digital Elevation Model (DEM). Topographic relief is related to population distribution and economic development: The higher the relief, the lower the population density. Thus we argue that population density under the influence of topography can represent the level of transportation demand and economic growth. China's terrain pattern is a natural phenomenon not directly related to transport demand or economic growth; thus, average elevation can be used to deal with the endogeneity problem (Dai et al. 2016).

In this paper, four groups of estimation models will be constructed and presented to test the impact of transportation investment on economic performance in China at the provincial level. The panel data are extracted from the China Statistical

Table 1 Definitions and descriptions of independent and explanatory variables, 1997–2015. *Source*: Calculated by the authors based on the China Statistical Yearbook from 1997 to 2015 (http://www.stats.gov.cn/), and China's Digital Elevation Model (http://www.dsac.cn)

Variable	Definition	Mean	Std. Dev.	Min.	Max.	Expected sign
ECON (¥ billion)	GDP	990.81	11,759.8	7.70	7281.26	
RTI (¥ billion)	Transportation investment	484.32	556.93	0.07	307.44	+
RNTI (¥ billion)	Non-transportation investment	507.64	7142.86	2.38	4459.40	+
RLAB (million)	Number in labor force aged 15–65	22.84	1579.11	1.18	62.23	+
LEL (m)	Average elevation above mean sea level	924.94	1022.67	3.71	3916.82	−
QSTA	Spatial stratified heterogeneity *q*-statistic	0.28	0.02	0.25	0.32	±
RURBAN (%)	Urban population as a percent of total	42.05	0.183	9.78	89.60	+

Yearbook from 1997 to 2015, focusing on 31 provincial units in mainland China. Hong Kong, Macao, and Taiwan are excluded because data is unavailable on a consistent basis (Table 1).

3.4 Model specification

The *q*-statistic (QSTA) measures the economy-based spatial heterogeneity in each province in China. If the *q*-statistic is 0, it means that there is no stratified heterogeneity; if QSTA = 1, it means that there is fully stratified heterogeneity (Wang et al. 2016).

$$\mathrm{QSTA} = 1 - \frac{1}{N\sigma^2}\sum_{h=1}^{L} N_h \sigma_h^2 \tag{1}$$

where N denotes the number of provinces in the study area ($N = 31$) and can be allocated to one of three ($h = 1$, 2, or 3) strata. The three strata correspond to Eastern, Middle, and Western China[1]. Thus N_h denotes the number of units in each of h strata, and σ_h^2 is the variance of GDP in each stratum. The variance of the gross domestic product of N is σ^2.

The primary form of the production function model is shown below without considering the spatial interaction effects.

$$\mathrm{ECON}_{ij} = f\left(\mathrm{TI}_{ij},\ \mathrm{NTI}_{ij},\ \mathrm{LAB}_{ij},\ \mathrm{QSTA}_{ij},\ \mathrm{ELE}_{i},\ \mathrm{URBAN}_{ij}\right) \tag{2}$$

[1] According to differences in topography and economic development, Mainland China is usually divided into Eastern China (EC), Central China (CC) and Western China (WC). In this study, EC includes Beijing, Tianjin, Hebei, Shandong, Jiangsu, Shanghai, Zhejiang, Fujian, Guangdong, Hainan; CC includes Liaoning, Jilin, Heilongjiang, Inner Mongolia, Shanxi, Henan, Anhui, Hubei, Jiangxi, and Hunan; the remainder belongs to WC.

The logarithmic form of the equation is constructed through a natural logarithmic transformation.

$$\begin{aligned} \ln\text{ECON}_{ij} = \beta_1 \ln\text{TI}_{ij} + \beta_2 \ln\text{NTI}_{ij} + \beta_3 \ln\text{LAB}_{ij} + \beta_4 \ln\text{ELE}_i \\ + \beta_5 \text{QSTA}_{ij} + \beta_6 \ln\text{URBAN}_{ij} + \mu_{ij} + \varepsilon_{ij} \end{aligned} \tag{3}$$

where i denotes the province and j denotes the year; β_i is the coefficient of each independent variable; μ_{ij} reflects the unobservable effects while ε_{ij} is the residual stochastic disturbance term.

In this paper, we use "GeoDa" software to create an original spatial weights matrix $\boldsymbol{W}$ based on rook contiguity describing the spatial arrangement of all 31 units, where $w_{ij} = 1$ if province i and province j are geographically adjacent, otherwise $w_{ij} = 0$.

$$w_{ij} = \begin{cases} 1, & i \text{ and } j \text{ are adjacent} \\ 0, & i \text{ and } j \text{ are NOT adjacent} \end{cases} \tag{4}$$

As the index of spatial autocorrelation, Global Moran's I index is calculated to determine whether it is necessary to use spatial econometric models (Yu et al. 2013). The index measures the spatial autocorrelation of both the independent and explanatory variables.

$$\text{Global Moran's}\, I = \frac{\sum_{i=1}^{n} \sum_{j=1}^{n} w_{ij}(Y_i - Y^*)(Y_j - Y^*)}{S^2 \sum_{i=1}^{n} \sum_{j=1}^{n} w_{ij}} \tag{5}$$

where Y_i is the value of a variable in region i; Y^* is the mean of Y_i; $S^2 = \frac{1}{n}\sum_{i=1}^{n}(Y_i - Y^*)$; $Y^* = \frac{1}{n}\sum_{i=1}^{n} Y_i$; w_{ij} is determined by Eq. 4.

Spatial econometric models are used to understand the effects of variable TI, which includes spatially weighted-independent variables as well as explanatory variables (Belotti et al. 2016). Equation 6 shows a spatial econometric model in its most basic form.

$$y_{i,j} = \rho \boldsymbol{W} y_{i,j} + \beta \boldsymbol{X}_{i,j} + \theta \boldsymbol{W}\boldsymbol{X}_{i,j} + \varepsilon_{i,j} \tag{6}$$

where $y_{i,j}$ is the dependent variable, namely the GDP of region i in year j. $\boldsymbol{W}$ denotes the $n \times n$ spatial weights matrix, which is normalized before estimating the transportation investment's impacts on economic growth considering spatiotemporal heterogeneity. In view of the proximity of Hainan and Guangdong and their closely linked and interdependent economic activities, Hainan is regarded as an adjacent neighbor of Guangdong, even though they do not share a land boundary. $\boldsymbol{W}y_{i,j}$ and $\boldsymbol{W}\boldsymbol{X}_{i,j}$ denote the spatially weighted-dependent and weighted-independent variables, respectively. ρ is the regression coefficient of $\boldsymbol{W}y_{i,j}$, and a positive or negative ρ indicates a positive or negative spatial correlation of regional economic development. The coefficient θ of $\boldsymbol{W}\boldsymbol{X}_{i,j}$ captures the spillover effects of the independent variables. The core research goal is to estimate the coefficient of the spatially weighted-independent variable of transportation investment ($\boldsymbol{W}$*lnTI). Equation 6 is then logarithmically transformed.

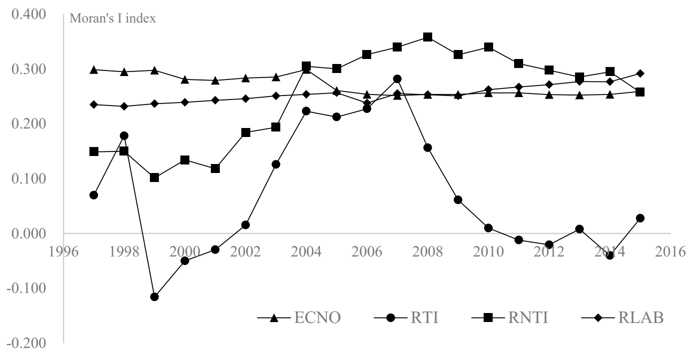

Fig. 4 Moran's *I* index of the ECON, RTI, RNTI, and RLAB variables. *Source*: Calculated in GeoDa by authors

$$\ln y_{ij} = \rho \boldsymbol{W} \ln y_{ij} + \beta \ln \boldsymbol{X}_{ij} + \theta \boldsymbol{W} \ln \boldsymbol{X}_{ij} + \varepsilon_{ij} \tag{7}$$

Given the time lag to design, construct, and operationalize transportation facilities, it is important to examine the economic effects of transportation investment after controlling the economic benefits yielded by transportation investment at the previous stage. Equation 8 is employed to test the one-year lag effects of transportation investment.

$$\ln y_{i,j} = \rho \boldsymbol{W} \ln y_{i,j} + \beta_i \ln \boldsymbol{X}_{i,j} + \theta \boldsymbol{W} \ln \boldsymbol{X}_{i,j} + \beta_0 \ln \mathrm{TI}_{i,j-1} + \beta_1 \boldsymbol{W}\mathrm{TI}_{i,j-1} + \varepsilon_{i,j} \tag{8}$$

We employ the "xsmle" package in "STATA 14.0" to estimate all the parameters (Belotti et al. 2016). This package allows us to test the coefficients based on different models: spatial autoregressive model (SAR), spatial Durbin model (SDM), spatial autocorrelation model (SAC), spatial error model (SEM), and generalized spatial random-effects model (GSRM). For a pooled dataset, three statistical models estimate the coefficients: the random-effects model, the fixed-effects model, and the random-fixed-effects model. In this paper, the choice among SAR, SDM, SAC, and SEM depends on testing the ρ and θ coefficients. The SDM was finally selected for further estimation since the model results indicate that $\rho \neq 0$ and $\theta \neq 0$. Whether to use the fixed effects or random-effects model was determined by using the robust Hausman's test (He 2008; Belotti et al. 2016). The fixed-effects models show the goodness of fit after reviewing the Hausman's test ($p < 0.05$). The following section will show the results based on the above estimations after a brief summary of China's transportation investment processes.

4 Results

4.1 The total effects of transportation investment

The global Moran's *I* index of the independent variable and the explanatory variables indicates that the lnECON and lnRLAB variables both show significant positive

Table 2 Estimation results of all samples after accounting for spatial interaction effects

Variables	Model 1 Pooled OLS	Model 2 Panel fixed effects	Model 3 SDM with spatial fixed effects
lnRTI	0.142***	0.103***	0.008
lnRNTI	0.231***	0.272***	0.074***
lnRLAB	0.675***	1.333***	0.471***
lnELE	−0.089***		
lnQSTA	−1.462***	−1.031***	0.195
lnRURBAN	0.720***	0.361***	0.047*
ρ			0.606***
$\boldsymbol{W}$*lnRTI			0.038***
$\boldsymbol{W}$*lnRNTI			0.009*
$\boldsymbol{W}$*lnRLAB			−0.028
$\boldsymbol{W}$*lnQSTA			−0.709***
$\boldsymbol{W}$*lnRURBAN			0.119*
Obs.	589	589	589
R_w^2	0.965	0.952	0.975
F test	2698.93***	2189.61***	
Log likelihood			481.656***

*$p<0.10$, **$p<0.05$, and ***$p<0.01$

spatial autocorrelation (Fig. 4). The variable lnRNTI represents positive spatial autocorrelation with significant fluctuations. The independent variable lnRTI shows both positive and negative spatial autocorrelation at different periods. These results show that it is necessary to consider spatial autocorrelation to better estimate the economic effects of transportation investment.

Table 2 shows the estimation results of different regression models. The pooled OLS model shows that transportation investment has significant positive effects on economic performance, and the coefficient of variable lnRTI is 14.2% at the 1% significance level. When compared with the effects of non-transportation investment (the coefficient of lnRNTI is 23.1%) and size of the labor force (the coefficient of lnRLAB is 67.5%), it is apparent that the effect of transportation investment on regional economic growth is still quite limited. The coefficient of lnELE is negative, indicating that the topography of the terrain between and within provinces is not conducive to inter-provincial economic linkages and as a result, it may limit the economic effects of transportation investment. In contrast to the pooled OLS model, the lnELE variable is removed in Models 2 and 3. Compared with Models 1 and 2, the coefficient of lnQSTA in Model 3 becomes positive, which indicates that spatial heterogeneity could serve as an opportunity to enhance the transportation investment's economic impact when considering the issue of spatial autocorrelation. The fixed effects panel model still indicates the considerable benefits of transportation investment; it is even less than that in the pooled OLS model.

The impact of transportation investment and its significance decrease when the issue of spatial autocorrelation is taken into account. Based on the ρ and θ coefficients, the SDM was selected to test the economic impacts of transportation investment. In Model 3, the coefficient of lnRTI is only 0.8% and insignificant, while the coefficient of $\boldsymbol{W}$*lnRTI is 3.8% and significant at the 1% level. Wetwitoo and Kato (2017) observed that transportation investment can increase productivity through the impacts of agglomeration. While transportation investment can promote both the magnitude and the spatial concentration of economic development, the results outlined in Table 2 indicate that the magnitude and significance of the economic impacts of transportation investment decrease, when the spatial correlation is incorporated in the model. In accounting for these results, we should recall that the economic impact of transportation investment depend not only on the volume of investment but also on the effect of implementation and operation of the transportation infrastructure projects. The Moran's I of the transportation investment (TI) from 1997 to 2015 indicates that some regions are highly invested in transportation facilities, while neighboring regions are underinvested. In this case, the underinvested transportation infrastructure in neighboring regions may serve as barriers to economic growth.

4.2 The effects in subregions

The multi-level impacts of transportation investment are sensitive to the methodology used in the analysis, and the economic impacts can vary significantly by geographical scale (Chen and Haynes 2015). From a regional perspective, both economic growth and transportation investment are unevenly distributed with notable contrasts between China's coastal and interior regions. Under these circumstances, the improvement of transportation linkages would significantly affect population migration and flows of economic activities. For example, transportation investment in Xinjiang contributes to polarization in the central area and promotes the social and economic development of peripheral regions through direct or indirect effects (Wang and Zhang 2010).

In this section, we construct a set of spatial panel regression models to illustrate the effects of transportation investment (lnRTI) on economic growth in different regions compared to other factors related to non-transportation investment (lnRNTI) and the labor market (lnRLAB). In these models, the performance of the economy (lnECON) is the dependent variable.

Due to differences in topography and economic development, the economic effects of transportation investment vary across regions. In general, improvements in accessibility tend to have a negative impact on the convergence of the regional economy. In other words, transportation investment causes the economic gap between developed and less developed regions to expand.

The economic effects of transportation investment in western, middle, and eastern areas are shown in Table 3 and two findings stand out. First, similarities with Table 2 indicate that the economic effect of transportation investment is much lower when the issue of spatial autocorrelation is incorporated. In eastern

Table 3 The economic effects of transportation investment in different regions

Variables	West region			Middle region			East region		
	Model 4 Pooled OLS	Model 5 Panel fixed effect	Model 6 SDM with spatial fixed effects	Model 7 Pooled OLS	Model 8 Panel fixed effect	Model 9 SDM with spatial fixed effects	Model 10 Pooled OLS	Model 11 Panel fixed effect	Model 12 SDM with spatial fixed effects
lnRTI	0.03	0.013	−0.006	0.132***	0.122***	0.065**	0.158***	0.122***	0.096***
lnRNTI	0.371***	0.310***	0.034	0.216***	0.268***	0.103***	0.167***	0.224***	0.166***
lnRLAB	0.643***	2.674***	−0.116	0.724***	1.482***	0.475***	0.788***	1.528***	1.510***
lnELE	0.064*			0.051			−0.077***		
lnRURBAN	0.429***	0.177*	−0.047	0.734***	0.231**	0.005	0.684***	0.189**	0.273***
ρ			0.446***			0.487***			0.199***
W*lnRTI			0.029			−0.021			−0.016
W*lnRNTI			0.117***			0.021			−0.009
W*lnRLAB			2.600***			1.006***			−0.272***
W*lnRURBAN			−0.038			0.137			−0.112**
Obs.	209	209	209	190	190	190	190	190	190
R_w^2	0.969	0.959	0.983	0.939	0.944	0.964	0.959	0.944	0.947
F	1283.55***	1140.95***		584.21***	747.18***		874.08***	743.77***	
Log likelihood			185.167***			116.912***			83.85***

$*p<0.10$, $**p<0.05$, and $***p<0.01$

areas, for instance, the coefficients of lnRTI are estimated to be 15.8%, 12.2%, and 9.6% using pooled OLS, panel fixed effects, and the spatial Durbin model, respectively. Second, the economic effects of transportation investment decrease from east to west. The coefficient of lnRTI is both positive and significant in eastern (9.6%) and middle areas (6.5%), while in western regions, the coefficient is − 0.6%, indicating that transportation investment in relatively developed regions will have a greater impact on economic growth than in less developed regions. These findings are corroborated in other work on the impact of transportation investment in hinterland regions (Jiang et al. 2016; Baum-Snow et al. 2018). The regional difference in transportation investment efficiency may also account for the observed disparities in growth across regions (Li et al. 2016). The coefficient of workforce lnRLAB is positive and significant in all models, which is consistent with the labor-oriented character of economic growth in China.

These different geographical effects may be crucial in regional or local planning and investment decisions related to transportation infrastructure. The high level of urbanization in eastern and central regions means that economic activities and individuals would benefit from a transportation system with high accessibility and connectivity, and in turn, transportation investment can further promote their economic development. For many underdeveloped provinces in China's western areas, the economy is more reliant on labor-intensive sectors and on non-transportation investment (e.g., investment in agricultural and industrial sectors). Meanwhile, considering the economic gap between China's western and eastern regions, transportation investment would accelerate the transfer of economic opportunities from western into middle or eastern regions, exacerbating east–west development disparities.

From the spatial aspect, the coefficient of ***W****lnRTI in the west region is positive, but it is negative in both central and eastern regions. It indicates that as an economic growth tool, transportation investment would lead to the spatial decentralization of economic activities in central and eastern regions, in addition to the spatial centralization observed in the west region. Several factors may account for this phenomenon. In China's middle or coastal regions, due to the potential negative externalities of high density development, a high level of urbanization and well-rounded transportation infrastructure would facilitate the relocation and spatial decentralization of economic activities, as an attempt to lower their operating costs. For instance, in China's developed Pearl River Delta, the improved high-speed rail transit services at the metropolitan help promote the relocation of certain firms from central Shenzhen to its neighboring peripheral areas, such as the Dongguan, Huizhou, or Shanwei (Lin et al. 2018). In underdeveloped regions, the population distribution may be quite scattered due to the constraints of topography. In such a case, the cities or regions with the highest population density or economic performance would be given high priority for transportation investment. In those underdeveloped areas, as a result, the improved transportation conditions would lead to the spatial concentration of economic activities.

Table 4 The spillover effects of transportation in different periods

Variables	Period I: 1997–2006			Period II: 2007–2015		
	Model 13 Pooled OLS	Model 14 Panel fixed effect	Model 15 SDM with spatial fixed effects	Model 16 Pooled OLS	Model 17 Panel fixed effect	Model 18 SDM with spatial fixed effects
lnRTI	0.0701***	−0.009	0.008	0.259***	0.070***	0.025
lnRNTI	0.188***	0.079***	0.033***	0.178***	0.045***	0.031***
lnRLAB	0. 795***	0.454***	0.352***	0.555***	1.010***	0.702***
lnELE	−0.107**			−0.067***		
lnQSTA	−0.271	3.121***	−0.188	−0.954***	−2.663***	−1.08
lnRURBAN	0.641***	−0.011***	0.174	1.037***	1.084***	0.979***
ρ			0.438***			0.599***
W*lnRTI			0.009			−0.006
W*lnRNTI			0.027*			0.008
W*lnRLAB			−0.250*			0.156
W*lnQSTA			1.745***			0.282
W*lnRURBAN			−0.017			−0.756***
Obs.	310	310	310	279	279	279
R_w^2	0.951	0.958	0.961	0.972	0.969	0.974
F test	1004.29***	1234.08***		1583.74***	1524.80***	
Log likelihood			400.05***			450.178***

*$p < 0.10$, **$p < 0.05$, and ***$p < 0.01$

4.3 The variances in different periods

To estimate the temporal heterogeneity of transportation investment's impacts on economic performance between 1997–2006 and 2007–2015, six models have been estimated to provide indirect measures of how upgraded transportation infrastructure can impact economic performance and its spatial agglomeration. All of the models in Table 4 show the same overall trend: The coefficient of lnRTI significantly increases as the economy develops, indicating that the effectiveness of transportation investment grows steadily as the economy grows and transportation infrastructure is upgraded. In Model 15, the coefficient of ***W****lnRTI is positive but not significant, and it becomes negative when estimated using Model 18 in period II. This finding reflects the potential of transportation investment to change the spatial dimension of the regional economy from spatial concentration to decentralization. The past decade has seen the rapid growth of HSR in China. In the process of investment in the transportation sector, the improvement of transportation infrastructure has enabled a variety of economic activities to transfer across regions to new locations with lower costs and higher productivity. Overall, this process will help to decrease the spatial concentration of economic activities.

Table 5 The economic effects of transportation considering time lagged effect

Variables	Model 19 Pooled OLS	Model 20 Pane fixed effect	Model 21 SDM with spatial fixed effects
lnRTI	0.110***	0.089***	0.004
lnRNTI	0.172***	0.233***	0.074***
lnRLAB	0.662***	1.158***	0.458***
$\ln RTI_{i-1}$	0.118***	0.101***	0.032***
lnELE	−0.094***		
lnQSTA	−1.494***	−1.085***	−0.734***
lnRURBAN	0.696***	0.288***	0.037
ρ			0.579***
W*lnRTI			0.042***
W*lnRNTI			0.022
W*lnRLAB			−0.009
W*$\ln RTI_{i-1}$			−0.001
W*lnQSTA			0.184
W*lnRURBAN			0.115*
Obs.	589	589	589
R_w^2	0.968	0.958	0.977
F test	2585.89***	2096.29***	
Log Likelihood			491.29***

*$p<0.10$, **$p<0.05$, and ***$p<0.01$

4.4 The spillover effects considering the time lag effects

Transportation systems promote economic growth in two different ways. First, public infrastructure is a kind of investment that induces economic growth. Second, the transportation system has a significant network effect by reducing transportation costs and enhancing accessibility which improves production efficiency, an effect that diffuses to adjacent areas. Transportation investment has time lag effects because it often takes several years from the inception of planning to the start of operations. For instance, the impacts of transportation investment on employment and economic growth would be significantly decreased after considering the time lag effects (Hakim and Merkert 2016). Hence, it is necessary to study the effects of previous transportation investment and economic performance on future economic development.

The regression models in Table 5 estimate the economic role of variables lnTI and $\ln TI_{i-1}$. All models show that both past and present transportation investments have significant effects on economic performance, and the role of current investment is slightly lower than previous investment. However, compared with non-transportation investment and labor conditions, whether existing or former transportation investment, the role is quite limited. For instance, the SDM with spatial fixed effects show that the coefficient of lnRLAB is 45.8%, much higher than any other variable. Furthermore, it points out that China's economic development is still in a labor-intensive stage.

After controlling for the spatial autocorrelation effects, SDM with spatial fixed effects indicates that the coefficient of lnRTI is positive and significant. The coefficient of lnRTI_{i-1} is positive but insignificant and much larger than lnTI. This result shows that as an economic growth tool, transportation investment at the previous stage would have more significant effects on economic performance than the same investment at the current stage. The spatial error coefficient ***W****lnRTI is positive, but ***W***$^*\text{lnRTI}_{i-1}$ is negative, indicating that current transportation investment would help the spatial concentration of economic activities, but the spatial pattern becomes decentralized when the transportation investment at the previous stage is considered.

Transportation investment also has significant positive effects on the growth rate of production in either direct or indirect ways (Legaspi et al. 2015; Rokicki and Stępniak 2018; Penyalver et al. 2019). For instance, Holmgren and Merkel (2017) found that the economic effect of transportation infrastructure investment ranges from −0.06 to 0.52. Similarly, Yu et al. (2012) investigated the role of transportation investment in promoting economic growth using provincial panel data from 1978 to 2008 and found that the estimated effect (output elasticity) of transportation capital was 0.13 at the national level. This effect increases to 0.17 after incorporating the effect of spatial autocorrelation (Yu et al. 2013). Compared with results from other relevant studies (Yu et al. 2012, 2013; Cigu et al. 2019), the coefficient of transportation investment found in this research is much lower. To a certain extent, the economic impact of transportation investment in China is decreasing. These differences may be attributed to different study time-span, variables employed, and test models selected. Another possible explanation is that the role of other variables (e.g., investment in other sectors, labor conditions, or market environment) is dramatically increased by using recent data to assess the effect of transportation investment, causing the consequences of transportation investment to appear lower. For example, given its large scale and maintenance costs, the performance and efficiency of transportation investment may become limited (Farhadi 2015; Vickerman 2018).

5 Discussion and conclusion

After jointly considering the spatial autocorrelation issues and effectively addressing the endogeneity problem, this paper constructs provincial panel dataset including transportation investment, labor market, and economic conditions in China's provincial level from 1997 to 2015, to evaluate the impact of transportation investment on economic performance. The results show that: (1) significant economic growth and spatial aggregation effects of transportation investment are found in this study. In general, the effects decrease after controlling for spatial autocorrelation; (2) economic effects of the investment in transport sectors have considerable spatial and temporal differences. For areas with a higher level of urbanization, the economic impact of transportation investment is much larger, and to some extent, it can promote economic clustering and the formation of large conurbations. The temporal effects show that transportation investment reinforced the scale and spatial aggregation effects of regional development. Transportation investment in the first period (1997–2006) has greater effects on economic growth, resulting in the spatial decentralization of economic activities. The results suggest that both central and local governments should carefully evaluate the multifaceted economic effects of transportation investment, such as a balanced transportation investment and economic development between growing and lagging regions, and considering the spatiotemporal heterogeneity of the economic environment.

Compared to previous findings (Zhang 2008; Yu et al. 2012, 2013), this research finds that the economic impact of transportation investment is decreasing. To a certain extent, it supports the recent arguments that efficiency of transportation investment may become limited given the high operating and maintenance costs (Farhadi 2015; Vickerman 2018). Under this trend, large-scale transportation investment decisions should not be undertaken until the issue of efficiency and equity arguments have been carefully evaluated (Zhou 2016; Kyriacou et al. 2019), as such public expenditures may be subject to public scrutiny and criticism as well. One potential trend based on the above analysis is that transportation investment will be most effective in regions with a high level of urbanization and industrialization. Considering the potential expansion of investment in the transportation sectors, careful evaluation of investment strategies and plans is essential to meet the requirements for accessibility in different regions and to enhance investment efficiency. The results reported here have two significant policy implications for decision-making on transportation investment and regional growth in other developing countries or regions, particularly those involved in the Belt and Road Initiative.

First, the effect of transportation investment on economic growth has both temporal and spatial heterogeneity, which shows the importance of determining reasonable investment scale based on the level of economic growth and transportation demand. In addition, the regression results based on Models 5 and 13 indicate the greater effectiveness of transportation investment in fostering economic growth in developed regions. This might help to explain the lack of investment in lagging regions and is of significance to secure more investment in these areas to promote a more even distribution of transportation infrastructure at the national level and reduce the level of regional disparity.

Second, a single form of transportation investment has a limited impact on economic growth. Investments in multiple transportation modes are essential to enhance accessibility and mobility across regions through network effects to reduce transportation costs. The role of transportation investment not only reflects the scale of investment but the quality and effectiveness of transportation investment. Transportation investment also has a significant role in shaping the spatial form, land use pattern and land value. In response to traffic congestion, it should assign a high priority to investment in public transportation. It is worth mentioning that a better multi-level governance framework can promote the effectiveness of transportation investment at the regional scale (Lin et al. 2018).

This research does have certain limitations. First, the measures of transportation investment used in the panel data models do not distinguish among the investment impacts of different transportation modes, such as roadway, marine and inland shipping, commercial aviation or HSR. Second, the various impacts of existing capital stock and new investment in transportation need to be tested at the local scale (e.g., city or county scale). Third, this research uses the value of transportation investment as one explanatory variable but fails to capture the mechanisms of economic growth supported by the accessibility improvements. The improved accessibility, rather than the investment value, would generate different impacts on the city or regional economic development. Fourth, the long-run economic development and locational effects of transportation investment in reducing transportation costs should be further evaluated. To effectively overcome these deficiencies, more refined assessment methods are required to assess the effectiveness of transportation investment under various temporal–spatial conditions and economic development stages.

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Compliance with ethical standards

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References

Achour H, Belloumi M (2016) Investigating the causal relationship between transport infrastructure, transport energy consumption and economic growth in Tunisia. Renew Sustain Energy Rev 56:988–998

Alonso W (1964) Location and land use: towards a general theory of land rent. Harvard University Press, Cambridge

Andrejić M, Bojović N, Kilibarda M (2016) A framework for measuring transport efficiency in distribution centers. Transp Policy 45:99–106

Ansar A, Flyvbjerg B, Budzier A, Lunn D (2016) Does infrastructure investment lead to economic growth or economic fragility? Evidence from China. Oxf Rev Econ Policy 32(3):360–390

Aschauer DA (1990) Highway capacity and economic growth. Econ Perspect 14(5):4–24

Baum-Snow N, Henderson JV, Turner MA, Zhang Q, Brandta L (2018) Does investment in national highways help or hurt hinterland city growth? J Urban Econ. https://doi.org/10.1016/j.jue.2018.05.001

Belotti F, Hughes G, Mortari PA (2016) Spatial panel data models using Stata. CEIS Tor Vergata Res Pap Ser 14(5):1–38

Berechman J, Ozmen D, Ozbay K (2006) Empirical analysis of transportation investment and economic development at state, county and municipality levels. Transportation 33(6):537–551

Beyzatlar MA, Karacal M, Yetkiner H (2014) Granger-causality between transportation and GDP: a panel data approach. Transp Res Pt A-Policy Pract 63:43–55

Canning D, Fay M (1993) The effect of transportation networks on economic growth. Columbia University discussion paper series. https://academiccommons.columbia.edu/doi/10.7916/D80K2H4N. Accessed 28 May 2019

Chakrabarti S (2018) Can highway development promote employment growth in India? Transp Policy 69:1–9

Chen Z, Haynes KE (2015) Multilevel assessment of public transportation infrastructure: a spatial econometric computable general equilibrium approach. Ann Reg Sci 54(3):663–685

Chen Z, Haynes KE (2017) Impact of high-speed rail on regional economic disparity in China. J Transp Geogr 65:80–91

Chen C, Vickerman R (2017) Can transport infrastructure change regions' economic fortunes? Some evidence from Europe and China. Reg Stud 51(1):144–160
Chen J, Chen J, Miao Y, Song M, Fan Y (2016) Unbalanced development of inter-provincial high-grade highway in China: decomposing the Gini coefficient. Transp Res Part D Transp Environ 48:499–510
Cigu E, Agheorghiesei DT, Gavriluță AF, Toader E (2019) Transport infrastructure development, public performance and long-run economic growth: a case study for the Eu-28 countries. Sustainability 11(1):67–90
Dai Y, Xiao J, Pan Y (2016) Can "local accent" reduce agency cost? A case based on the perspective of dialects. Econ Res J 12:147–161
Démurger S (2001) Infrastructure development and economic growth: an explanation for regional disparities in China? J Comp Econ 29(1):95–117
Deng T (2013) Impacts of transport infrastructure on productivity and economic growth: recent advances and research challenges. Transp Rev 33(6):686–699
Diao M (2018) Does growth follow the rail? The potential impact of high-speed rail on the economic geography of China. Transp Res Pt A-Policy Pract 113:279–290
Eberts RW (1990) Public infrastructure and regional economic development. Econ Rev 26(1):15–27
Elburz Z, Nijkamp P, Pels E (2017) Public infrastructure and regional growth: lessons from meta-analysis. J Transp Geogr 58:1–8
Farhadi M (2015) Transport infrastructure and long-run economic growth in OECD countries. Transp Res Pt A-Policy Prac 74:73–90
Fujita M, Krugman PR, Venables AJ (1999) The spatial economy: cities, regions and international trade. MIT Press, Cambridge
Hakim MM, Merkert R (2016) The causal relationship between air transport and economic growth: empirical evidence from South Asia. J Transp Geogr 56:120–127
He C (2008) Foreign manufacturing investment in China: the role of industrial agglomeration and industrial linkages. China World Econ 16(1):82–99
Holmgren J, Merkel A (2017) Much ado about nothing? A meta-analysis of the relationship between infrastructure and economic growth. Res Transp Econ 63:13–26
Holtz-Eakin D, Schwartz AE (1995) Spatial productivity spillovers from public infrastructure: evidence from state highways. Int Tax Public Financ 2(3):459–468
Jia S, Zhou C, Qin C (2017) No difference in effect of high-speed rail on regional economic growth based on match effect perspective? Transp Res Pt A Policy Pract 106:144–157
Jiang X, Zhang L, Xiong C, Wang R (2016) Transportation and regional economic development: analysis of spatial spillovers in China provincial regions. Netw Spat Econ 16(3):769–790
Jiang X, He X, Zhang L, Qin H, Shao F (2017) Multimodal transportation infrastructure investment and regional economic development: a structural equation modeling empirical analysis in China from 1986 to 2011. Transp Policy 54:43–52
Kim BHS, Kim E (2015) Human capital and spatial development in Northeastern Asian regions. Ann Reg Sci 55(2–3):265–268
Kim E, Hewings GJD, Amir H (2017) Economic evaluation of transportation projects: an application of financial computable general equilibrium model. Res Transp Econ 61:44–55
Knowles DR, Ferbrache F (2016) Evaluation of wider economic impacts of light rail investment on cities. J Transp Geogr 54:430–439
Kyriacou AP, Muinelo-Gallo L, Roca-Sagalés O (2019) The efficiency of transport infrastructure investment and the role of government quality: an empirical analysis. Transp Policy 74:93–102
Legaspi J, Hensher D, Wang B (2015) Estimating the wider economic benefits of transport investments: the case of the Sydney North West Rail Link project. Case Stud on Transp Policy 3(2):182–195
Li T, Yang W, Zhang H, Cao X (2016) Evaluating the impact of transport investment on the efficiency of regional integrated transport systems in China. Transp Policy 45:66–76
Lin X, Yang J, MacLachlan I (2018) High-speed rail as a solution to metropolitan passenger mobility: the case of Shenzhen–Dongguan–Huizhou metropolitan area. J Transp Land Use 11(1):1257–1270
Maparu TS, Mazumder TN (2017) Transport infrastructure, economic development and urbanization in India (1990–2011): is there any causal relationship? Transp Res Pt A-Policy Pract 100:319–336
Melo PC, Graham DJ, Brage-Ardao R (2013) The productivity of transport infrastructure investment: a meta-analysis of empirical evidence. Reg Sci Urban Econ 43(5):695–706
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

Ministry of Transport of China (2017) The total transport investment will reach 15 trillion during the 13th five-year plan period. http://finance.sina.com.cn/roll/2017-02-28/doc-ifyavwcv9136677.shtml. Accessed 12 Dec 2018
Nocke V (2006) A gap for me: entrepreneurs and entry. J Eur Econ Assoc 4(5):929–956
Ozbay K, Ozmen-Ertekind D, Berechman J (2007) Contribution of transportation investments to county output. Transp Policy 14(4):317–329
Penyalver D, Turró M, Williamson JB (2019) Measuring the value for money of transport infrastructure procurement: an intergenerational approach. Transp Res Pt A-Policy Pract 119:238–254
Pereira AM, Roca-Sagales O (2003) Spillover effects of public capital formation: evidence from the Spanish regions. J Urban Econ 53(2):238–256
Rokicki B, Stępniak M (2018) Major transport infrastructure investment and regional economic development: an accessibility-based approach. J Transp Geogr 72:36–49
Rothengatter W (2017) Wider economic impacts of transport infrastructure investments: relevant or negligible? Transp Policy 59:124–133
Sharif A, Shahbaz M, Hille E (2019) The transportation-growth nexus in USA: fresh insights from pre-post global crisis period. Transp Res Pt A-Policy Pract 121:108–121
Shi Y, Guo S, Sun P (2017) The role of infrastructure in China's regional economic growth. J Asian Econ 49:26–41
Stepniak M, Rosik P (2013) Accessibility improvement, territorial cohesion and spillovers: a multidimensional evaluation of two motorway sections in Poland. J Transp Geogr 31:154–163
Sun Y, Cui Y (2018) Analyzing urban infrastructure economic benefit using an integrated approach. Cities 79:124–133
Tokunova G (2018) Assessment of the transport infrastructure influence on urban agglomerations development. Transp Res Proc 36:754–758
Vickerman R (2018) Can high-speed rail have a transformative effect on the economy? Transp Policy 62:31–37
Wang B, Zhang X (2010) The contribution of the highway to economic growth in Xinjiang based on I–O and ESDA. Acta Geogr Sin 65(12):1522–1533
Wang J, Zhang T, Fu B (2016) A measure of spatial stratified heterogeneity. Ecol Indic 67:250–256
Wetwitoo J, Kato H (2017) Inter-regional transportation and economic productivity: a case study of regional agglomeration economies in Japan. Ann Reg Sci 59(2):321–344
Yu N, de Jong M, Storm S, Mi J (2012) The growth impact of transport infrastructure investment: a regional analysis for China (1978–2008). Policy Soc 31:25–38
Yu N, de Jong M, Storm S, Mi J (2013) Spatial spillover effects of transport infrastructure: evidence from Chinese regions. J Transp Geogr 28:56–66
Zhang X (2008) Transport infrastructure, spatial spillover and economic growth: evidence from China. Front Econ China 3(4):585–597
Zhou J (2016) The transit metropolis of Chinese characteristics? Literature review, interviews, surveys and case studies. Transp Policy 51:115–125
Zong G, Wu H (2011) Transport investment and economic growth in Beijing city. Prices Monthly 1:56–59

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