

Article

The Impact of Transport Infrastructure Investment on Energy Intensity: The Perspective of Fiscal Decentralization

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Abstract: Investment in China's transport infrastructure has contributed to its rapid economic growth, which also consumes a great deal of energy and generates a significant amount of carbon emissions. In these circumstances, it is worthwhile to discuss the internal influence mechanisms behind these two outcomes' similar growth trends. This paper selects panel data from 30 regions in China from 2009 to 2019 and uses the threshold spatial autoregressive (TSAR) model to analyze the impact of transport infrastructure investment on the energy intensity due to fiscal decentralization. While studies of the relationship between transport infrastructure investment and energy intensity exist, few studies examine the non-linear spatial relationship between the two. This paper fills this gap by using the TSAR Model. The results show the following: (1) the effect of transport infrastructure investment on the energy intensity under fiscal decentralization and heterogeneity expresses non-linear characteristic; (2) there is a positive relationship between infrastructure investment and energy intensity when the degree of attenuation is low, but when the degree of attenuation is higher than a particular threshold value, transport infrastructure investment negatively impacts energy intensity; (3) rising energy prices, increasing investment in technological innovation costs, and increasing foreign trade will help to drive the decline in energy intensity.

Keywords: transport infrastructure investment; fiscal decentralization; energy intensity; threshold spatial autoregressive model (TSAR)



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1. Introduction

Global climate and health issues have emerged as a significant challenge post-COVID-19. At the 75th session of the United Nations General Assembly, the General Secretary of the Chinese Communist Party and President of China, Xi Jinping, proposed the goals of “carbon neutrality by 2030” and “carbon neutrality by 2060” based on China's national conditions. In 2020, China's central economic work conference explicitly listed “double-carbon” work as one of the eight key construction projects. The implementation of dual-carbon projects is full of opportunities and challenges. Promoting an energy transformation and reducing energy intensity has become a meaningful way to rely on the dual-carbon target [1].

With the decentralization of power from the central government to local governments, local governments have the primary responsibility for economic development within their jurisdiction [2]. A typical case is that fiscal decentralization has increased the fiscal revenue of local governments [3], and local governments have begun to expand various infrastructure investments to achieve rapid economic growth in their regions; at the same time, fiscal decentralization has brought an increase in energy consumption. To gain a deeper understanding of the impact of transportation infrastructure on energy intensity, this paper incorporates fiscal decentralization into its analysis framework.

In addition to analyzing the mechanism role of fiscal decentralization in the relationship between transportation infrastructure and energy intensity, two important issues should be noted: spatial and threshold effects. Local CO₂ emissions can be affected by spatial effects in two ways [4,5]. One is that the carbon dioxide gas from other provinces

flows into the local area; the other is that the energy transition in other places can have a demonstration effect, affecting the local energy transition and thus affecting the local energy intensity. The threshold effect is the difference in the degree of fiscal decentralization in various provinces, and the effect of transportation infrastructure investment on energy intensity is different. Local governments with higher fiscal decentralization have more fiscal revenues for investment in their transportation infrastructure, which may significantly impact their regions' energy intensity. To further analyze the impact mechanism of transportation infrastructure investment on energy intensity, both spatial effects and threshold effects should be considered.

The contribution of this paper is reflected in the following three aspects. First, although many studies have analyzed the spatial spillover effects of energy intensity, they have ignored the non-linear spatial relationship between transportation infrastructure investment and energy intensity. Second, some literature separately analyzes the impact of transportation infrastructure investment and fiscal decentralization on energy intensity. Our article takes fiscal decentralization to be an instability factor and analyzes its role in the transmission path, which helps us to have a deeper understanding of the non-linear relationship between transportation infrastructure investment and energy intensity. Third, we use a novel empirical model called the threshold spatial autoregressive model (TSAR). This model can analyze the spatial heterogeneity between variables, so that the threshold effect and spatial effect are estimated in one equation, and the result is robust.

We use the TSAR model to analyze the impact of transportation infrastructure investment on energy intensity under different degrees of fiscal decentralization. We examined the non-linear spatial relationship between transportation infrastructure investment and energy intensity, and we also found that the degree of fiscal decentralization affects the mechanism between transportation infrastructure investment and energy intensity. Policy implications of these results suggest that the central government should pay attention to the role fiscal decentralization plays in the impact of transportation infrastructure investment on energy intensity.

The rest of this paper is structured as follows. Section 2 briefly reviews the existing literature. Section 3 includes the research methods and variable descriptions, which use the TSAR model to investigate the impact of transport infrastructure investment on energy intensity from the perspective of fiscal decentralization. Section 4 analyzes the empirical results using panel data from 30 provinces in China to analyze the impact of transport infrastructure investment on energy intensity at different degrees of fiscal decentralization. Section 5 provides the conclusions and policy implications. The final section discusses the limitations of this study.

2. Literature Review

This section reviews the factors influencing energy intensity—especially the research on the relationship between transportation infrastructure investment and energy intensity—and analyzes the role of fiscal decentralization in this relationship. At the end of this section, the progress of this article compared with the existing literature is given.

2.1. Studies on the Factors Affecting Energy Intensity

Many scholars have completed deep research into the factors influencing energy intensity, but the conclusions are different because of differences in theory and empirical methods. In the existing literature [6], scholars first studied the relationship between economic growth and energy structure, which showed a positive correlation between economic scale and energy factor consumption, which in turn led to a decline in environmental quality. To analyze the impact of railway, highway, aviation, and waterway per capita transportation mileage on energy intensity, Li et al. [7] combined the autoregressive distribution lag (ADL) with the vector error correction model (VECM) to examine China's data from 1985 to 2013. Some researchers [8] analyzed the impact of foreign investment and technology and believe that foreign investment may improve technology, but also that its

spillover effect inhibits the reduction of energy intensity. Predrag Petrovic [9] analyzed the imbalanced panel data of 36 EU countries from 1995 to 2015 and found that the main factors driving energy intensity were industrial output, real GDP per capita, and retail prices of petroleum. Although many factors have supported China's energy intensity during the past four decades of rapid economic growth, transport infrastructure construction is considered essential [10–12]. Many studies have demonstrated that transport infrastructure investment plays a positive role in economic growth [13]. However, the rapid development of China's economy, including its transport infrastructure investment as its main driving force, has taken its toll on the environment [14]. Therefore, it is necessary to analyze the relationship between transportation infrastructure investment and energy intensity.

2.2. Studies on the Impacts of Transportation Infrastructure Investment on Energy Intensity

There have also been many different conclusions regarding mechanisms in the impact of transport infrastructure investment on energy consumption. From a theoretical perspective, some studies provided evidence that transport infrastructure investment achieved green development through a knowledge spillover [15] and green innovation [16]. Lin and Chen [17] found that transport infrastructure investment reduced the energy intensity of China's manufacturing industry in the long term. Wetwitoo and Hulten et al. [18,19] discovered that the productivity in developed areas was higher, and higher productivity could mean a lower energy intensity. Glaeser and Kahn [20] believed that the production costs saved could be allocated to energy-preserving technology, thus affecting energy efficiency. On the contrary, there is evidence that excessive transport infrastructure investment leads to massive energy consumption, ultimately leading to a double increase in energy intensity. According to the *China National Ecological Environment Circular* (2019), the width of the road has a significant negative impact on PM10, and although rail transit has an air-pollution-reducing effect in the long run, the construction of rail transit has a negative short-term effect on air quality.

In terms of quantitative research, empirical findings suggested that the inverse U-shaped inflection point of the Kuznets curve was used to study the non-linear relationship between transport infrastructure and energy consumption [21,22]. In areas with a high level of transportation infrastructure, increased investment can improve the infrastructure conditions in a region, and the scale effect of transportation infrastructure construction and the application of new technologies can also promote a reduction in energy consumption. However, for regions with a low level of transportation infrastructure, inter-provincial coordination is poor, and it is difficult to form a scale effect, resulting in investment in transportation facilities that can increase energy consumption. Moreover, from agglomeration economics theories, the energy intensity of different provinces has a spatial spillover effect, which can be tested by spatial econometrics [23]. The quadratic function only assumes a non-linear relationship between transport infrastructure and energy consumption. It is rare to start from estimating the data itself to verify the non-linear relationship between transport infrastructure and energy intensity. However, there are short works of literature that put the two effects into an econometric model for comprehensive estimation.

2.3. Studies on the Roles of Fiscal Decentralization in the Path of “Transport Infrastructure Investment—Energy Intensity”

Some studies also found that fiscal decentralization caused the local government to invest excessively in transport infrastructure for economic growth, and this action has squeezed the investment of the environmental protection department [24].

When China regulates energy intensity, the central government generally formulates unified policies, and local governments implement the policies. Due to their assessment and competition, local governments can be affected by many factors, resulting in differences in the supervision of energy intensity in different provinces. First, the importance of economic growth in the promotion and evaluation of officials is infinitely magnified, and local governments can blindly increase investment in transportation infrastructure; it can also reduce local governments' emphasis on energy consumption to stimulate the local eco-

economic growth [25,26]. Second, to stabilize their tax revenue and reduce the transportation costs of local enterprises, local governments can increase investment in transportation infrastructure and ignore energy intensity [27]. Third, local governments increase investment in transportation infrastructure and carry out differentiated competition to attract more enterprises. Neighboring provinces can also imitate, attracting new enterprises and seeking economic development by increasing their investment in transportation infrastructure [28]. However, the existing literature rarely analyses the impact of transport infrastructure investment on energy intensity and the path of fiscal decentralization [29].

Although different regression approaches were applied in previous studies—such as the mediating effect model, moderating effect model, and system dynamics model—these methods ignore spatial effects. There is no research in the existing literature on the non-linear spatial relationship between transportation infrastructure and energy intensity. In contrast, our model can analyze the spatial heterogeneity between transportation infrastructure investment and energy intensity, so that the threshold and spatial effects are estimated in one equation. In terms of economic theory, since the general spatial measurement models are linear assumptions, they cannot explain the asymmetric policy responses of local governments. Investment in transportation infrastructure is increasing, but there are significant differences in energy intensity. As China's regional economic development is unbalanced, the fiscal power of local governments is also different. The TSAR model can estimate the non-linear relationship in space, that is, considering the role of the different financial powers of local governments on transportation infrastructure investment in their effects on the relationship between transportation infrastructure investment and energy intensity.

3. Econometric Methodology

Based on works in the literature [11], we present the panel data model:

$$EI_{it} = \beta_0 TI_{it} + \lambda X_{it} + \alpha_0 + \delta_t + u_i + \varepsilon_{it} \quad (1)$$

where EI_{it} represents the energy intensity of province i at time t , TI_{it} represents the investment intensity of province i at time t , X_{it} is a vector composed of a set of control variables, δ_t represents the time effect, and u_i represents the personal effect.

Some investigations also showed that due to the existence of fiscal decentralization, to stimulate economic growth local governments can increase investment in transport infrastructure and squeeze investment in environmental pollution such as R&D expenditure. Thus, different degrees of decentralization can affect the impact of transport infrastructure investment on energy efficiency. We adopted the threshold regression model with panel data (TR) to investigate its impact on energy intensity and established the following TR:

$$EI_{it} = \sum_{m=1}^M \beta_m TI_{it} \cdot I(fd_{it} \in [\gamma_{m-1}, \gamma_m]) + \lambda X_{it} + \alpha_0 + \delta_t + u_i + \varepsilon_{it} \quad (2)$$

In this formula, FD_{it} means the degree of fiscal decentralization of province i at time t and $I(\cdot)$ is the indicative function.

Some scholars gave evidence that TI is an essential factor affecting energy intensity. However, energy intensity is affected by some other economic factors within the region. It is also affected by the spatial correlation of carbon emissions in the adjacent area [29]. Thus, we introduced the spatial lag of energy intensity based on Equation (2). Since the threshold variables in this paper act on the explanatory variables, the existing theory has not yet given the estimation method of the spatial Durbin model in the case of multiple thresholds. Therefore, we established the following TSAR model based on the previous literature and existing theories:

$$EI_{it} = \rho W \cdot EI_{it} + \sum_{m=1}^M \beta_m TI_{it} \cdot I(fd_{it} \in [\gamma_{m-1}, \gamma_m]) + \lambda X_{it} + \alpha_0 + \delta_t + u_i + \varepsilon_{it} \quad (3)$$

Here, W represents the spatial weight matrix. Thus, we take the spatial lag terms of the energy intensity (El_{it}) into the model to research the spatial spillover effects of the energy intensity.

3.1. Spatial Weight Matrix

There are three main methods to construct spatial weight matrices: spatial adjacency, economic distance, and geographical distance. However, compared with economic distance and geographical distance, the spatial adjacency matrix is sparse. The storage space can be saved without changing the contents and information of the original spatial matrix, and the speed and efficiency of the spatial metrological model analysis can be improved [30]. Therefore, this paper selects the spatial adjacency matrix as the spatial weight matrix of empirical research. The general expression for constructing the spatial adjacency weight matrix is:

$$W_{ij}^G = \begin{cases} 1, & i \text{ is adjacent to } j \\ 0, & i \text{ is not adjacent to } j \end{cases} \quad (4)$$

3.2. Variable and Data

The dependent variable of this paper is the provincial energy intensity, the core independent variable is transport infrastructure investment, the threshold variable is fiscal decentralization, and the other variables are control variables.

3.2.1. Dependent Variable: Energy Intensity

Based on the definition of the statistical indicator, this paper defines energy intensity as the ratio of the primary energy consumption to real GDP.

3.2.2. Independent Variable: Investment in Transport Infrastructure

There are three methods to measure transport infrastructure investment: stock, public, and fixed asset. As a large amount of private capital participates in the investment in transport infrastructure, it is more appropriate to choose the fixed assets investment index for transport infrastructure. For this reason, this paper refers to the definition of transport infrastructure investment in the *World Development Report 1994: Infrastructure for Development* published by the World Bank. In the selection of indicators in the study by Liu Ming et al., the fixed assets investment of “transportation, warehousing, post and telecommunications” is selected as the index to analyze.

3.2.3. Threshold Variable: Fiscal Decentralization

Presently, the measurement of fiscal decentralization is mainly divided into three measurement methods: fiscal revenue decentralization, fiscal expenditure decentralization, and fiscal autonomy. To reflect regional differences in fiscal relations, this paper refers to the measurement methods of Chen Shuo et al. [31]. The degree of budgetary autonomy is chosen as the quantitative index of fiscal decentralization, defined as the ratio between the fiscal revenue and total fiscal expenditure in the provincial budget.

3.2.4. Control Variables

According to Shen Xiaobo et al. [32,33], the first control variable is the energy price index. When the energy price rises, each master will reduce its energy consumption to drive a reduction in the energy cost under the condition of a constant output. It has been shown that the energy price index harms energy intensity [34]. Since technological innovation significantly affects energy efficiency improvement, the second control variable selects R&D expenditure intensity to measure technological progress. The literature verifies that increasing R&D expenditure can promote technological progress and cause a drop in energy intensity [35]. In addition to fostering independent innovation through internal R&D costs, external channels such as foreign investment and international trade also play an essential role in technological innovation [36]. The theory of economic growth holds that foreign

investment and foreign exchange have a spatial spillover effect and that technologically backward countries improve their domestic technical level by imitating the technology of advanced countries [37,38], thus contributing to a decline in energy intensity. Based on this, this paper selects foreign investment and imports and exports as control variables. The variable description is shown in Table 1.

Table 1. Variable description and data processing.

Variable Name	Symbols	Variable Processing
Energy intensity	<i>EI</i>	The ratio of primary energy consumption to real GDP.
Investment intensity of transport infrastructure	<i>TI</i>	The ratio of fixed-asset investment to real GDP in transportation, warehousing, and postal services.
Fiscal decentralization	<i>FD</i>	The ratio of the fiscal revenue in the budget at the corresponding level to the total fiscal expenditure in the budget at the corresponding level.
Energy price index	<i>Price</i>	Fuel price index in the provincial commodity retail price index.
R&D spending intensity	<i>Rd</i>	The ratio of R & D expenditure to GDP.
Intensity of foreign trade	<i>Trade</i>	The ratio of total imports and exports to GDP.
Intensity of foreign investment	<i>FDI</i>	The ratio of FDI to GDP.

3.3. Data Sources

This paper selects data from 30 provinces in China from 2009 to 2019 (excluding Hong Kong, Macao, Taiwan, and Tibet). The data in Table 1 are mainly from the wind database and CEIC China Economic Database. The data on transport infrastructure investment after 2018 were calculated according to the growth rate in the statistical bulletin of each province. The statistical descriptions of the variables are shown in Table 2.

Table 2. Descriptive statistics of variables.

Variable	Obs.	Mean	S.d.	Min.	Max.
EI	330	0.843	0.453	0.208	2.503
TI	330	0.069	0.039	0.016	0.278
FD	330	0.502	0.192	0.148	0.931
Price	330	1.193	0.100	1.000	1.391
Rd	330	0.016	0.011	0.003	0.063
Trade	330	0.263	0.283	0.011	1.428
FDI	330	0.021	0.016	0.001	0.082

3.4. Threshold Effect Test

The number of possible thresholds M and the values of the thresholds γ needed to be solved before estimating the model's regression (3). In the study of the threshold effect, Hansen's theory [39] was used to search for the threshold values based on the idea of a minimum sum of squares of residuals.

The bootstrap method was used to simulate the asymptotic distribution and the critical values of the LR test. The results of the threshold effect and the threshold values are shown in Table 3.

Table 3. Test of FD's threshold effect.

M	γ	F -Value	p -Value	BS	Critical Value		
					1%	5%	10%
Single threshold	0.292	125.413	0.000	300	33.803	38.156	48.257
Double threshold	0.515	67.129	0.003	300	25.377	31.803	47.899
Triple threshold	0.213	42.701	0.387	300	80.699	93.915	122.451

Note: M is the number of thresholds; γ is the value of the threshold.

The results in Table 3 show that the p -value of the triple threshold was 0.387, which is not significant at the level of 10%. In comparison, the estimate of the double threshold was essential at the level of 1%, which indicates the existence of a double-threshold effect. Therefore, when fiscal decentralization was used as the threshold variable, a threshold effect of transport infrastructure investment on energy intensity existed, indicating that transport infrastructure investment's impact on energy intensity changed twice. It also shows that the impact of transport infrastructure investment on energy intensity can vary with the degree of fiscal decentralization. The interval classifications obtained for specific degrees of budgetary decentralization are shown in Table 4.

Table 4. Classification of fiscal decentralization based on the threshold values.

Interval	FD < 0.292	0.292 < FD < 0.515	0.515 < FD
Provinces	Guizhou, Yunnan, Inner Mongolia, Hainan, Shanxi	Heilongjiang, Jilin, Liaoning, Hebei, Anhui, Jiangxi, Ningxia, Shaanxi, Qinghai, Gansu, Henan, Hunan, Hubei, Chongqing, Sichuan, Guangxi, Xinjiang	Beijing, Tianjin, Shandong, Jiangsu, Zhejiang, Shanghai, Fujian, Guangdong

4. Empirical Analysis

4.1. Spatial Correlation Test

To test the spatial correlation of the explained variables and verify the rationality of using a spatial econometric analysis, this study used a spatial adjacency weight to measure the energy intensity of Moran's I in 30 regions of China from 2009 to 2019; results are shown in Table 5.

Table 5. Global spatial correlation test.

Year	Moran's I	Z-Value	Year	Moran's I	Z-Value
2009	0.406 ***	3.615	2015	0.422 ***	3.811
2010	0.407 ***	3.615	2016	0.427 ***	3.834
2011	0.404 ***	3.615	2017	0.446 ***	4.011
2012	0.407 ***	3.668	2018	0.450 ***	4.092
2013	0.414 ***	3.727	2019	0.456 ***	4.111
2014	0.420 ***	3.739			

Note: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$, Moran's I is the global Moran's statistic; z is the standardized global Moran's statistic obeying an asymptotic standard normal distribution.

As shown in Table 5, the energy intensity in the 30 regions in China was positive. At the 1% level, the significance test shows that energy intensity had a positive spatial correlation among provinces. The scatter plots of energy intensity in 2009 and 2019 are plotted in Figure 1 to vividly show the spatial correlation of energy intensity.

From Figure 1, it can be found that the energy intensity in the first and third quadrants was higher than that in the second and fourth quadrants. Provinces with low (high) energy intensity tended to cluster spatially. The spatial correlation of energy intensity was verified by calculating the Moran index and drawing the cluster graph.

4.2. Empirical Results and Discussion

The results of the Hausman test indicate that the fixed effects form was adopted in the panel data model. Table 6 analyzes the impact of transport infrastructure investment on energy intensity using the panel data model, the threshold regression model with panel data (TR), and the threshold spatial autoregressive (TSAR) model. Referring to the method of Kelejian and Chen [40,41], we used spatial two-stage least squares to estimate the TSAR.

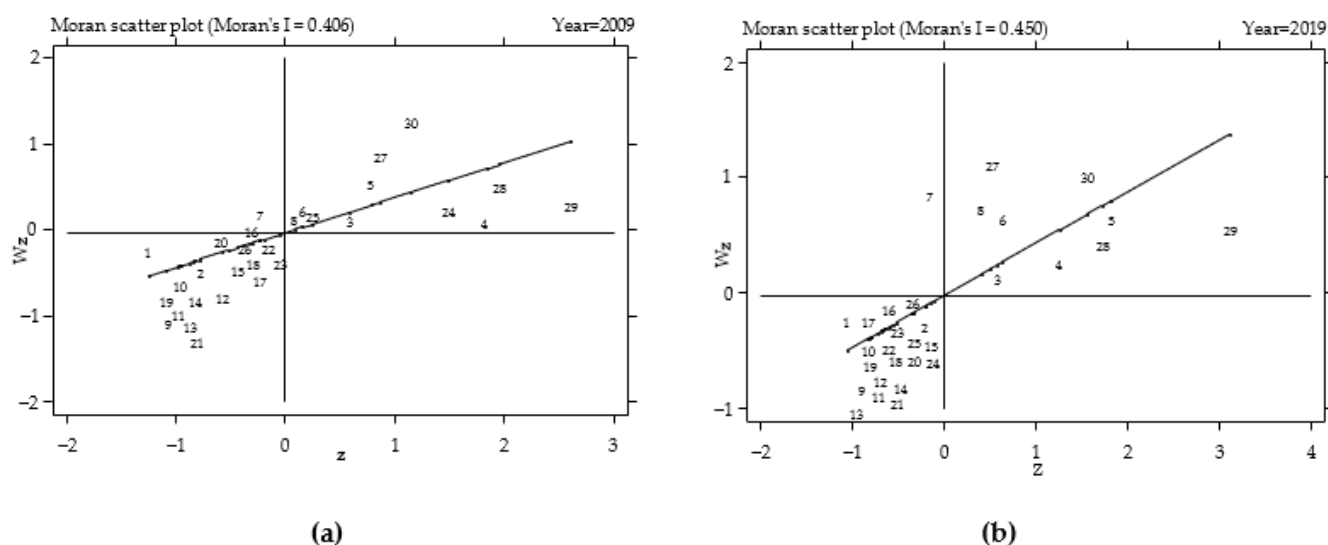


Figure 1. This is a set of Moran scatter plots. Here: (a) scatter plot of local Moran index of EI in 30 provinces of China in 2009; (b) scatter plot of local Moran index of EI in 30 provinces of China in 2019.

Table 6. Regression results of the model.

Variable	Panel Data	TR	TSAR
<i>TI</i>	1.6294 *** (0.297)	/	/
<i>TI1</i>	/	0.204 *** (0.025)	0.9708 *** (0.193)
<i>TI2</i>	/	0.8767 *** (0.215)	0.5119 *** (0.161)
<i>TI3</i>	/	−0.2478 *** (0.089)	−0.1442 ** (0.069)
<i>FD</i>	−12.3482 *** (4.177)	−5.3116 ** (2.116)	−3.3973 ** (1.564)
<i>Price</i>	−0.2663 *** (0.079)	−0.0010 ** (0.000)	−0.0456 *** (0.016)
<i>Rd</i>	−10.2509 ** (4.262)	−1.5924 ** (0.652)	−3.9296 ** (1.701)
<i>Trade</i>	−0.6942 *** (0.141)	−0.5406 *** (0.118)	−0.1427 ** (0.061)
<i>FDI</i>	0.5867 * (0.339)	0.1169 * (0.708)	0.5352 * (0.292)
<i>Cons</i>	2.0124 *** (0.108)	1.5267 *** (0.100)	/
ρ	/	/	0.4865 *** (0.048)
<i>R</i> ²	0.6614	0.7675	0.7905
<i>Time effect</i>	FE	FE	FE
<i>Entity effect</i>	FE	FE	FE
<i>Obs</i>	330	330	330

Note: standard errors are in parentheses—* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. ρ is the spatial autoregressive coefficient. FE is the fixed effect. We clustered standard errors at the city level where indicated.

The panel data model show that the impact coefficient of transport infrastructure investment on energy intensity was significantly positive at the 1% level, which indicates that the energy consumption increased with the increase in transport infrastructure investment. After adding the threshold effect, the model of TR is superior to the ordinary panel model's goodness of fit. A threshold regression model with panel data with the control variable FDI did not appear significant from the single-variable significance. Other variables show the importance of little change. In the panel data model, transport infrastructure

investment had a positive correlation with energy consumption. Under fiscal decentralization heterogeneity, transport infrastructure investment was still positively related to energy consumption in the first and second intervals. Still, in the third interval transport infrastructure investment was negatively correlated with energy intensity. However, the double-threshold model lacks a consideration of the spatial effect, so that it was mainly analyzed with TSAR.

The estimated results of TSAR in Table 6 show that the spatial lag ρ passed the significance test at the level of 1%, indicating a significant spatial spillover effect on energy intensity. This is also consistent with the conclusion that the energy intensity had an autocorrelation in space. According to the estimated coefficients of the threshold term, the impact of transportation infrastructure investment on energy intensity showed a non-linear trend. When the degree of budgetary decentralization was less than 0.292, each unit increase in transportation infrastructure investment was associated with a 0.9708 unit increase in energy intensity. When the degree of fiscal decentralization broke through the first threshold, the impact of transportation infrastructure investment on energy intensity decreased. Each additional unit of transport generated 0.5119 units of energy intensity. When the intensity of fiscal decentralization further expanded and broke through the second threshold, the effect of transportation infrastructure investment on energy negatively impacted the slight positive impact. This stage of development can be understood as follows: with the expansion of local financial power, the increase in the scale of transport infrastructure investment to increased energy intensity underwent an inevitable slowdown. Liu and Elheddad also found a non-linear relationship between fiscal decentralization and energy consumption [42–44].

According to the new economic geography theory, with the impact of transportation costs, material resources, human resources, and other factors on space, energy consumption can also move spatially, resulting in an inverted U-shaped change in energy intensity in space. Based on the empirical results in Table 6, double thresholds of fiscal decentralization and their effects on the energy intensity of transport infrastructure investment are gradually weakened. It can be understood that there is an inverted U-shaped trend of energy intensity in transport infrastructure investment. Numerous theories and studies have shown that fiscal decentralization and transport infrastructure investment impacted positively on energy intensity. Given a negative relationship between transport infrastructure investment and energy intensity when the degree of decentralization was higher than the second threshold, Kuby and He [45] believed that local governments had increased the amount of debt issuance and corporate tax incentives to attract a group of low-energy, high-tech companies to settle in the local area, which had a high degree of decentralization, and could increase investment in transport infrastructure to reduce the transport costs of foreign enterprises, allowing these areas to produce lower energy emissions. On the other hand, introducing the technological level and economic benefits of these foreign companies could promote the energy transformation of local industries and further reduce the energy intensity. These areas are mainly distributed in eastern coastal provinces and cities.

4.3. Decomposition of Spatial Effects

For spatial econometric models, the effects of independent variables on dependent variables can be decomposed into direct effects, indirect effects, and total effects. The marginal effects should be judged based on the decomposed effects. Table 7 shows the direct, indirect, and total effects calculated based on the model estimates.

The results in Table 7 show that the spatial effects of transportation infrastructure investment on energy intensity were statistically significant under different degrees of decentralization. When the degree of fiscal decentralization was in the first and second interval, the increase in investment in transportation infrastructure in a region could not only increase its energy intensity; it could also have a positive impact on the energy intensity of the surrounding area. Specifically, for the Midwestern Sectional Figure Skating Championships, each percent increase in transport infrastructure investment in the surrounding

provinces would result in a 0.6 percent to 0.9 percent increase in the energy intensity of the province. In terms of the overall effect, an increase of 1% in the transportation infrastructure investment in the central and western regions would increase energy intensity by 1.21% to 1.71%. If investment in transportation infrastructure increased by 1% in the eastern region, energy intensity would drop by 0.58%.

Table 7. Spatial effect decomposition.

Variable	Direct Effect		Indirect Effect		Total Effect	
	Coefficient	S.d.	Coefficient	S.d.	Coefficient	S.d.
TI_1	0.8103 ***	0.171	0.9025 ***	0.214	1.7128 ***	0.366
TI_2	0.6219 ***	0.168	0.5897 ***	0.160	1.2116 ***	0.328
TI_3	−0.2015 **	0.081	−0.3829 **	0.158	−0.5844 **	0.234
FD	−1.0849 **	0.426	−1.1134 **	0.438	−2.1984 **	0.863
$Price$	−0.1771 ***	0.066	−0.2317 **	0.092	−0.4088 ***	0.155
Rd	−1.3657 ***	0.326	−2.5309 **	1.071	−3.8966 **	1.641
$Trade$	−0.2971 ***	0.088	−0.3908 ***	0.129	−0.6878 ***	0.211
FDI	−0.9283 *	0.491	1.2506 *	0.686	0.3223 *	0.173

Notes: standard errors are in parentheses—* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. ρ is the spatial autoregressive coefficient. FE is the fixed effect. We clustered standard errors at the city level where indicated.

For other control variables, energy prices, technological innovation, and foreign trade had a significant direct inhibitory effect on energy intensity directly and had a significant inhibitory effect on indirect effects. This shows that rising energy prices, increasing investment in technological innovation, and increasing foreign trade can benefit energy intensity. The direct effect of foreign investment on energy intensity was negatively correlated. However, the indirect effect was positively correlated, and the significance was not exceptionally high, indicating that the entry of foreign investment did not achieve the expected decline in energy intensity through technology-spillover effects. On the contrary, the overall effect was positively correlated, indicating that foreign investment had a negative impact on the overall energy intensity of a region.

4.4. Robustness Test

To verify the rationality of the TSAR model and the robustness of the conclusions, this study performed regression tests by changing the index of the fiscal decentralization measure and spatial weight matrix. First, we used Xu's method [46] of fiscal decentralization measurement for local governments to replace Chen and others' fiscal decentralization measurement methods. Second, the spatial weight matrix used in the TSAR model was transformed from the spatial adjacency method to the geographical distance weight matrix for regression. Third, we performed the regression again by adding two control variables, which are the population density and the GDP per capita.

The regression results in Table 8 show that there were still double thresholds in the replaced financial decentralization indicators. The symbols and signs of the regression coefficient of energy intensity for transport infrastructure investment did not change substantially in each interval. That is to say that there was an inverted U-shaped trend of energy intensity in transport infrastructure investment.

Table 8. Robustness tests.

Variable	Different Fiscal Decentralizations		Different Spatial Weight Matrices		Added Control Variables	
	Coefficient	S.d.	Coefficient	S.d.	Coefficient	S.d.
TI_1	1.0962 *	0.238	1.1164 **	0.232	1.9602 ***	0.426
TI_2	0.4172 ***	0.159	0.2967 **	0.146	0.3174 **	0.127
TI_3	−0.4559 **	0.181	−0.4066 *	0.232	−0.5546 **	0.220
FD	−3.0912 **	1.018	−6.0448 **	3.078	−3.6683 ***	0.612
$Price$	−0.1424 **	0.057	−0.0973 ***	0.037	−0.0314 *	0.016
Rd	−3.4696 **	1.550	−2.6498 **	1.196	3.1123 **	1.291
$Trade$	−0.2219 ***	0.086	−0.1169 *	0.061	−0.1103	0.069
FDI	0.3234	0.217	0.1935	0.151	0.6679	0.612
$PGDP$	—	—	—	—	0.0427 ***	0.007
PD	—	—	—	—	−1.5604 ***	0.119
ρ	0.6098 **	0.041	2.1164 ***	0.153	0.610	0.041
R^2	0.7363		0.7451		0.7399	
Time effect	FE		FE		FE	
Entity effect	FE		FE		FE	
Obs.	330		330		330	

Notes: standard errors are in parentheses—* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. ρ is the spatial autoregressive coefficient. FE is the fixed effect. We clustered standard errors at the city level where indicated.

5. Conclusions and Policy Implications

5.1. Conclusions

This study selected panel data on transport infrastructure investment and energy intensity in 30 regions of China from 2009 to 2019 and tested the threshold effect and spatial correlation. By analyzing the empirical results, the main conclusions are as follows.

First, transportation infrastructure investment significantly impacted energy intensity, and this effect was non-linear in space. Specifically, there was a positive relationship between transportation infrastructure investment and energy intensity. However, transportation infrastructure investment always negatively affected energy intensity when decentralization was higher than a certain threshold, which was mainly manifested in China's eastern coastal provinces and cities.

Second, investment in transport infrastructure directly affected energy intensity and had a significant adverse impact on reducing energy intensity through indirect effects. The direct and indirect effects of transportation infrastructure investment on energy intensity were both positive. Nevertheless, for provinces with a high degree of fiscal decentralization, the direct and indirect impacts showed opposite conclusions. This conclusion could be explained as follows: that an increase of 1% in transport infrastructure investment would increase energy intensity by approximately 1.2116% to 1.7128%.

Third, energy price, technology innovation, and foreign trade had significant inhibitions on energy intensity, but the relationship between foreign investment and energy intensity is uncertain.

Fourth, the neglect of non-linear relationships in space could lead to biased regression results.

5.2. Policy Implications

The conclusion of this paper enables us to put forward some targeted policy recommendations to improve the policy design of the Chinese government and provides references for local governments with different levels of fiscal decentralization.

First, the central government should attach importance to investment in transportation infrastructure in the central and western regions and decentralize some fiscal powers, giving them to local governments. The central government could also give local governments certain powers in the issuance of bonds and tax collection, and improve the audit and supervision mechanism, so that fiscal decentralization can truly bring dividends for the central and western regions in attracting investment and at the same time strengthen

the migration of high-tech industries to stimulate the technological innovation of local enterprises and promote the conservation of energy and reduction of emissions.

Second, the central government could increase high-speed rail investment in the central and western regions. Furthermore, local governments could also guide residents to use high-speed rail as their primary mode of travel. For the inverted U-shaped inflection point for transportation infrastructure investment to arrive as soon as possible, governments at all levels should comprehensively formulate plans based on financial conditions to increase the incentive system for eastern technical personnel to support the western region, improve energy efficiency in the central and western regions, and reduce energy intensity.

Third, the local governments could actively reform energy prices and use energy price control mechanisms to reduce energy consumption. At present, in addition to coal having achieved a market-oriented mechanism, other energy prices are still under the government's macro-control. The central government should speed up the formulation of the carbon trading system and improve the carbon market pricing mechanism and regulatory mechanism. The government should also provide certain fiscal expenditures as extraordinary expenses for new energy research and development to accelerate the application of clean and renewable energy.

6. Discussion

To achieve more credible scientific research and stronger policy recommendations in this study, we discuss its limitations, which are detailed as follows.

First, although we have used the novel TSAR model to analyze the non-linear spatial impact of transportation infrastructure investment on energy intensity, due to the limitations of theoretical estimation methods we are currently unable to provide a comparison between the TSDM model and TSEM model, because in these models the method of estimating has not yet been studied. The TSAR is the most novel and appropriate among the existing models when analyzing the non-linear relationship in space.

Second, due to the difficulty of obtaining data, many variables have not been considered when selecting control variables in this study. Of course, when we were conducting research, we also excluded many control variables that did not meet the conditions. For example, there was multicollinearity among existing variables, and they were not significant after being added.

Third, this study analyzed the impact of transportation infrastructure on energy intensity. Provinces with a higher degree of decentralization had a negative impact on energy intensity. These provinces are mainly manifested in the eastern part of China. Based on this conclusion, this article makes the following bold conjectures: for some emerging economies, the degree of fiscal decentralization of local governments is low, and transportation infrastructure investment can have a positive relationship with energy intensity. That is, the environment will be polluted. For developed countries such as Europe and the United States, where fiscal decentralization is relatively high and technology is relatively advanced, investment in transportation infrastructure negatively correlates with energy intensity. In the future, we will collect data from various countries to analyze the relationship between transportation infrastructure investment and energy intensity in the context of fiscal decentralization heterogeneity.

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