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Can fiscal decentralisation regulate the impact of industrial structure on energy efficiency?

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ABSTRACT

This study applies the slack-based measure-data envelopment analysis (SBM-DEA) method to measure energy efficiency and tests the spatial spill-over effects of fiscal decentralisation, industrial structure and energy efficiency using the spatial Durbin model. The results show that China's energy efficiency presents a clear geographical step distribution, and the Eastern and Western regions have higher energy efficiency than the Central region. Fiscal decentralisation has a positive effect on the energy efficiency of the Eastern and Central regions by upgrading the industrial structure. In addition, fiscal decentralisation has significant, positive externalities on the surrounding areas, promoting environmental protection and energy conservation in all regions of China. The results are in line with the tenets of environmental federalism (Oates & Schwab): through the allocation and transfer of industrial factors, fiscal decentralisation affects energy governance. Therefore, local governments should formulate policies and targets according to their regions' different economic development levels, and the Central and Western areas, which have greater space for improvement and low energy efficiency, should receive attention to balance regional differences.

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1. Introduction

With the development of the global economy, the problems of resources, environment and ecology have become increasingly prominent (Wang et al., 2019; Yu & Liu, 2020). The extensive use of fossil energy has resulted in serious environmental pollution, which is contrary to the concept of sustainable development (Chakravarty & Kumar, 2020; Ma et al., 2017). Compared with renewable energy, traditional energy has presented decreased consumption over the past few years, but it is still the main energy source used in industrial production (Hadian & Madani, 2015). By 2018, solar and wind energy accounted for less than 4% of the energy consumption in the United States[1], and most of the energy consumed still comes from coal, oil and natural gas. Countries all over the world have long paid attention to energy (Su et al.,

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2020a). For example, at the European Parliament in 2009, the "Kyoto Protocol" and "the United Nations Framework Convention on Climate Change" committed to limiting greenhouse gas emissions and fostering energy efficiency. In 2015, the Paris Agreement recognised that fossil fuel combustion for energy production should be constantly reduced and finally stopped (Nowotny et al., 2018; Yoon et al., 2017). In recent years, with the imbalance of energy supply-demand, the pressure for energy conservation and emission reduction has increased (Yang et al., 2020). Energy consumption and influencing factors (Su et al., 2020b) has been considered to realise the win-win situation of environmental protection and economic growth. Therefore, improving energy efficiency is the focus of this paper.

The growth rate of the secondary industry in China has accelerated significantly, entailing the consumption of a large amount of energy (Chen et al., 2019). According to the BP World Energy Statistics Year book in 2019, China's share of global energy consumption increased from less than 6.10% in 1979 to 24% in 2018, making China the country with the largest increase in global energy consumption for 18 consecutive years (Wang, 2010; Yuan et al., 2017). In parallel, the energy problem has become increasingly prominent in China. First, the energy consumption structure is unreasonable, hindering China's technological progress and industrial structure improvement. In 2018, coal accounted for 59.0% of China's energy consumption, while natural gas, hydropower, nuclear power, wind power and other clean energy accounted for only 22.1%. Traditional energy is still mainly used for production. Second, the increase in demand led to the rapid growth of energy production and the obvious pressure of ecological environmental governance, seriously affecting the sustainable development of China's economy (Liang & Yang, 2019). Therefore, it is necessary for the government to undertake efforts to adjust the industrial structure and reduce pollutant emissions. A typical characteristic of China is that the government controls enormous productive sources and has a strong capability for interventions. Since 1994, China has formally implemented decentralisation reform, and local governments can directly influence the upgrading of industrial structures through policy implementation and management arrangements. Energy resources can be reallocated among various industrial sectors, with a significant impact on energy efficiency (Liu et al., 2017).

The study makes three contributions. First, we explain a new perspective of government fiscal decentralisation policies for interpreting the influences of industrial structures on energy efficiency. The existing literature is commonly based on the influencing channel of industrial structure adjustment, including industrial structure scale (Liu et al., 2020), industrial policy (Zhang et al., 2020), industrial structure upgrading (Zhu et al., 2019), *etc*. However, it is quite underdeveloped for interpreting the realities of China. Due to the depletion of fossil energy, the Chinese government implements policies that have been proved to influence energy efficiency (Bukarica & Robić, 2013; Zhao et al., 2020). The decentralisation of national finance can give full play to the implementation effect of industrial policies (Que et al., 2018) and increase local environmental governance (He, 2015). Hence, the explanation for the link of industrial structures with energy efficiency will be more convincing when considering fiscal decentralisation policies. This fact is also in line with environmental federalism

(Oates & Schwab, 1996) since fiscal decentralisation affects energy governance through the allocation and transmission of industrial factors. Second, energy efficiency heterogeneity is fully considered in our study. We also prove that the efficiency of China shows a clear geographical step distribution (Zhou et al., 2020), while the efficiency of the Eastern and Western areas is higher than in the Central areas. Finally, in the previous literature, the panel data model (Liu et al., 2020), Generalized Method of Moments (GMM) estimation system (He, 2015), and Tobit regression models (Li et al., 2013) have not noted the spatial spill-over effect on energy efficiency, which is difficult to hold in reality. In this paper, spatial Durbin model (SDM) is used to test the spatial spill-over effects of fiscal decentralisation and industrial structures on energy efficiency, which is an advantage of the model. The test results of spatial spill-over effect show that fiscal decentralisation has positive externalities on the surrounding areas, motivating the regions to protect the environment and increase energy output. Moreover, the factors influencing of energy efficiency in the Eastern and Central regions are more effective than those in the Western regions. This conclusion is helpful for the government to introduce targeted policies to improve regional energy efficiency.

The rest of this study is organised as follows. Section 2 covers the literature review. Section 3 outlines Environmental Federalism theory. Section 4 describes the methodology. Section 5 illustrates a description of the data. Section 6 presents a discussion of the empirical findings. Section 7 summarises the results and discusses some policy implications.

2. Literature Review

2.1. Fiscal decentralisation and energy efficiency

Whether fiscal decentralisation actually contributes to energy efficiency has long been debated, and both positive and negative hypotheses have emerged (Mohamed et al., 2020). To solve the energy problem, the treatment of ecological or environmental pollution factors must be considered by the government (Zhang et al., 2020). Based on the diffusion effect of environmental information and the scale effect of information collection, local governments are closer to the public within local geographical locations (Barseghyan & Coate, 2014; Larson & Soto, 2008), and this informational advantage allows the local government to provide more efficient public services and reduce the cost of environmental governance (Blomquist et al., 2010; Hayek, 1945). Brar and Singh (2014) also found that the fiscal decentralisation system is conducive to reducing the decision-making costs of local public affairs. Hottenrott and Rexhäuser (2015) found that financial decentralisation can encourage enterprises to develop environmental protection technology, thus reducing the cost of environmental damage. Since fiscal decentralisation can increase local revenue, Liu et al. (2019) suggested that the local government can take the initiative to improve public services, which will encourage enterprises to use cleaner production technologies and enhance environmental protection. Zhou et al. (2010) and Percival et al. (2013) also found that complete environmental protection policies can regulate enterprise behaviours and encourage the government to take charge of the environment. The formulation and implementation of China's policies are easily affected by the surrounding areas. Lopez (2011) and Zhang et al. (2020) considered the effect of fiscal decentralisation on neighbouring areas and found that local governments can cooperate to improve the ecological environment and social welfare and reduce loss of efficiency according to local conditions.

However, fiscal decentralisation lacks a restraint mechanism, preventing local governments from considering saving costs when addressing environmental problems (Neyapti, 2010). Costanza (2014) concluded that local governments can relax environmental supervision standards to attract more enterprises to invest in local areas. Kamwa (2012) suggested that local governments attract investment by relaxing environmental quality supervision and competitively reducing taxation, leading to worse environmental quality. Under the decentralised system, local governments have the right to improve local environmental standards, and polluting enterprises from developed areas can transfer to regions with low environmental standards. Levinson (2003) revealed that this phenomenon could eventually lead to deterioration of the whole region's environmental quality. If environmental protection is regarded as a public good, China's decentralised system could be considered the main reason for environmental pollution (He, 2015). The government sacrifices the environment for the sake of economic development in some areas (Guo & Zheng, 2012).

2.2. Industrial structure and energy efficiency

The important function of industrial structures is to realise the effective allocation of resources through the industry's own transformation; this process can obtain the maximum economic benefits from limited resources and improve energy efficiency (Su et al., 2019a; Zhu & Shan, 2020). In particular, accelerating the upgrading of industrial structures is an effective way to conserve energy and reduce emissions (Yu et al., 2016; Zhou et al., 2013). If an industry with high energy consumption grows faster than other industries, the energy efficiency of the whole national economy will decline (Shi, 2002). Considering that China's energy consumption intensity is greater than the world average, Zhao et al. (2010) pointed out that it is more effective to adjust the industrial structure by developing a low-carbon emissions industry than by adjusting the energy structure. Mi et al. (2015) also showed that a reasonable industrial structure can reduce energy intensity without hindering economic growth. While the average annual growth rate of the gross domestic product (GDP) of Beijing was 8.29% from 2010 to 2020, the adjustment of the industrial structure made it possible to conserve energy by 39.42%. In the process of rapid industrial structure change in China, there is inequality between regions. Tian et al. (2014) proved that the disparity in regional industrial structure substantially affects regional carbon emissions, and regions with relatively developed industrial structures are more likely to improve energy efficiency through advanced technology. Using the industrial data of 50 cities of different sizes in China from 2005 to 2014, Li et al. (2018) found that smaller cities cannot benefit from the externalities of industry agglomeration, leading to a reduction in energy efficiency, and secondary industries have the largest carbon emissions of the three industries (primary, secondary and tertiary industries[2]). The government should adjust the industrial structure with priority given to the tertiary industry to improve the energy efficiency of China's cities. Similarly, based on a case study of Jilin Province in China, Zhang et al. (2014) proposed the importance of increasing the proportion of tertiary industries in GDP to reduce carbon emissions. Cao et al. (2015) discovered that the upgrading of industrial structures would lead to serious air pollution in the short term, but in the long term, it would help to improve the environment. Chen and Jia (2017) found that an industrial structure dominated by heavy industry would aggravate haze pollution and cause low energy efficiency.

2.3. Fiscal decentralisation and industrial structure

Previous studies have offered mixed findings regarding fiscal decentralisation and industrial structures, concluding that the effects mainly depend on the negative or positive externalities of the decentralised system (Liu & Hu, 2017). On the one hand, under a system with fiscal decentralisation, the expansion of local government's disposable financial resources can bring technological progress, innovation and competition. To improve economic performance, local governments spare no effort to provide high-quality public goods and services for enterprises (Lu & Landry, 2014). Jia et al. (2014) observed that local officials are willing to invest more resources in infrastructure and attract mobile capital to promote the local economy. Jin et al. (2005) found that Chinese provincial governments considerably strengthen fiscal incentives, which are expected to promote local business development and generally advance provincial economic development and reform. Therefore, local governments in China rely on policy tools to promote industrial structure adjustment, the efficient allocation of various resource elements between industries and regions, and the upgrading of the regional industrial structure.

On the other hand, negative externalities of fiscal decentralisation regarding industrial structure persist. Under the system of fiscal decentralisation in China, local governments are free to choose policies according to their demand (Ding et al., 2019). To pursue capital investment and economic growth, governments intervene inappropriately in enterprises, which can cause the enterprises to lose their dominant positions. Tikiri (2009) suggested that grassroots public officials lack enthusiasm, leading to an increasing gap in the process of industrial transformation between regions and causes the resource allocation to deviate from the state necessary for industrial structure upgrading. Neyapti (2010) highlighted that local governments might lack economies of scale, so decentralisation could lead to vicious competition.

Compared with existing studies of energy efficiency, our study emphasises two aspects. First, China's energy efficiency has significant spatial characteristics (Wang et al., 2019, Feng & Wang, 2019). Therefore, it is necessary to study the current situation of China's energy efficiency, analyse the spatial characteristics of the system and the related economic factors(Su et al., 2020c; Su et al., 2020d), and propose relevant policy recommendations. Second, we emphasise the regulatory role of fiscal decentralisation. The aforementioned literature has discussed only the impact of fiscal decentralisation or industrial structure on energy, reaching no unified conclusion. As an important part of the institutional background in China, fiscal decentralisation inevitably adjusts the impact of industrial structure on energy efficiency. Few studies have examined the evolution of efficiency from the perspective of convergence.

3. The theoretical mechanism of environmental federalism

Based on the Cobb-Douglas production function (Phelps, 1957), we construct the short-term production function of an enterprise:

$$Q = F(K, L, E) = K^{\alpha} L^{\beta} e^{-\gamma} \tag{1}$$

where Q represents the economic output, K represents physical capital, L represents human capital, α is the share of physical in total output, β is the share of labour in total output, and output is positively related to capital input. e is the energy efficiency investment of the enterprise, and γ is the share of it in total output. The assumption is that the total investment of the enterprise remains unchanged in the short term. The enterprise invests limited funds into energy efficiency, which will inevitably produce a crowding out effect on the material capital investment. Since enterprises cannot directly increase output in the short term, energy efficiency investment has a negative impact on output. We include industrial structure G in Equation (2):

$$Q = GF(K, L, E) = GK^{\alpha} L^{\beta} e^{-\gamma} \tag{2}$$

With the reasonable adjustment of industrial structures, enterprises can be encouraged to increase energy efficiency investment, and the upgrading of industrial structure plays an important role in the increase of output (Jin et al., 2005).

Richard (1995) clearly put forward the ideology of allocation, income distribution and economic stability and advocated for a fiscal tax-sharing system. From the perspective of the three functions of financial resources, income distribution and economic stability, the latter two functions should be the responsibility of the central government, while resource allocation should be differently established according to the preferences of local residents. Therefore, the local government is suitable for resource allocation. Subsequently, environmental federalism (Oates, 2003; Oates & Schwab, 1996; Wilson, 1996) focuses on fiscal behaviours and the environmental impact under the decentralised system. By influencing the allocation of capital, technology, labour and other economic factors, fiscal decentralisation affects the structure and quality of regional economic development. As a by-product of economic output, pollution emissions are indirectly affected by economic policies. Environmental regulation takes effect by changing environmental standards and financial investment preferences (Su et al., 2019b). Equation (3) adds the policy variable τ (G) to the profit function of the enterprise; Equation (4) is the first-order condition for enterprises to pursue profit maximisation.

$$\pi = GK^{\alpha} L^{\beta} e^{-\gamma} - C(G) + \tau(G) \tag{3}$$

$$\partial\pi/\partial G = K^{\alpha}L^{\beta}e^{-\gamma} - C'(G) + \tau'(G) = 0 \tag{4}$$

In Equation (3), C (G) is the production cost of the enterprise. In Equation (4), we can observe that there is a complex relationship among policy, industrial structure and energy efficiency investment. On the one hand, regions with backward economic development levels and small market scales have difficulty attracting the flow of factors, and the industrial structure level is relatively low. For the sake of economic growth, the local government will introduce a large number of preferential policies to attract enterprises' investments. On the other hand, local governments might sacrifice resource consumption and environmental pollution to achieve GDP growth (Ma & Zhang, 2014).

4. Methods

In this paper, SDM is used to explore how the industrial structure affects energy efficiency under fiscal decentralisation (Song et al., 2018). Equation (5) represents the relationship between the industrial structure and energy efficiency. Equation (6) indicates that fiscal decentralisation not only can directly affect efficiency but also can adjust industrial structures. Substitute (6) into (5) to obtain the comprehensive model in Equation (7).

$$\text{Original model}: EE_{\text{it}} = c_0 + c1IS_{it} + \sum control_{it} + e_{it} \tag{5}$$

$$\text{Stochastic regulation effect model}: c_0 = \gamma_{00} + \gamma_{01}FD_{it} + \mu_{0it} \tag{6}$$

$$c_1 = \gamma_{10} + \gamma_{11}FD_{it} + \mu_{1it}$$

$$EE_{it} = \gamma_{00} + \gamma_{01}FD_{it} + \gamma_{10}IS_{it} + \gamma_{11}FD_{it} * IS_{it} + \sum control_{it} + \mu_{1it} * IS_{it} + \mu_{0it} + e_{it} \tag{7}$$

where EE represents energy efficiency. In fact, the emission of pollutants is inevitable in the process of energy consumption, which is an undesirable output. At the same time, when multiple decision-making units (DMUs) are effective (the efficiency value is 1), it cannot be further evaluated (Tone, 2002).Therefore, this paper innovatively adopts the super efficiency SBM-DEA model (Wang & Yang, 2019), which can obtain the corresponding technology frontier and efficiency evaluation in the case of unexpected output. FD is fiscal decentralisation, IS is industrial structure, and FD*IS is the interaction term of fiscal decentralisation and industrial structure. Control contains five variables: population density, trade openness, industrialisation, research and development (R&D), and GDP. γ is the elasticity coefficient, μ represents the individual effect, and e is the random error term. The residuals are $\text{e}_{\text{it}} \sim N(0, \sigma_e^2)$, $\mu_{kit} \sim N(0, \sigma_{uk}^2)$, and $\text{cov}(\mu_{kit}, \text{e}_{\text{it}}) = 0$.

Based on Equation (7), we write the SDM in Equation (8):

$$TE_{it} = \alpha_1 FD_{it} + \alpha_2 IS_{it} + \alpha_3 FD_{it} * IS_{it} + \alpha icontrol_{it} + \rho\sum_{j=1}^{n} w_{ij}TE_{jt} + \beta_1\sum_{j=1}^{n} w_{ij}FD_{jt} + \beta_2\sum_{j=1}^{n} w_{ij}IS_{jt} + \beta_3\sum_{j=1}^{n} w_{ij}FD_{jt} * IS_{jt} + \beta_i\sum_{j=1}^{n} w_{ij}control_{jt} + \mu_i + e_{it} \tag{8}$$

where $\sum w_{ij}TE_{jt}, \sum w_{ij}FD_{jt}, \sum w_{ij}IS_{jt}, \sum w_{ij}FD_{jt} * ISjt$ represent the spatial lag terms of energy efficiency, fiscal decentralisation, industrial structure and the interaction term, respectively. w_{ij} is the $n \times n$-dimensional spatial weight matrix, and we construct a new economic-adjacency compound spatial weight matrix; ρ, α and β represent the elasticity coefficients. Equation (8) considers the spatial correlation of dependent and independent variables (LeSage & Pace, 2009) and can be used to identify the spill-over effects of variables on efficiency.

The traditional adjacency space weight indicates that, if two spatial elements are adjacent, the matrix element is taken as 1; otherwise, it is taken as 0. However, this matrix has obvious shortcomings, showing that the interaction strength between two adjacent spatial elements is the same ($i.e, w_{ij} = w_{ji}$). In this paper, the upgrading of industrial structures can affect energy ecological efficiency through economic growth. In reality, the developed areas have stronger spatial impact and spill-over effects on the less developed areas. For example, the radiation impact intensity of Beijing on Hebei is obviously greater than that of Hebei on Beijing. Therefore, combining adjacency and economic matrices to construct composite spatial weight matrices can analyse the comprehensiveness and complexity of spatial effects (Case et al., 1993; Parent & LeSage, 2008). According to Li et al. (2010), we establish a new economic- adjacency compound spatial weight matrix:

$$W = W_d diag(\bar{Y}_1/\bar{Y}, \bar{Y}_2/\bar{Y}, L, \bar{Y}_n/\bar{Y}) \tag{9}$$

where Wd is the spatial weight matrix of geographical adjacency. $\bar{Y}_1 = 1/(t_1 - t_0 + 1)\sum_{t_0}^{t_1} Y_{it}$ is the average GDP of the i province. $\bar{Y} = \frac{1}{n(t_1-t_0+1)}\sum_{i-1}^{n}\sum_{t_0}^{t_1} Y_{it}$ is the average value of total GDP.

When the average GDP of spatial element i is greater than j, according to the matrix multiplication principle, W_d multiplies a diagonal matrix, and the elements on the diagonal line $\bar{X}_i/\bar{X}$ will correspondingly multiply each element in column i of W_d. The spatial weight matrix W can reflect the economic reality that regions with higher economic development level have stronger blessing effects on underdeveloped areas.

5. Data

This paper is based on the data of 30 administrative regions of mainland Chinese provinces for 1997-2017. Tibet was excluded because of a lack of data. The sources of data are the Chinese Energy Statistical Yearbook, China Environmental Statistical Yearbook, and China Statistical Yearbook (Statistical Yearbook of the Chinese

Investment in Fixed Assets and Provincial Statistical Yearbook). In 1997, the Chinese government closed 84,000 industrial enterprises with backward technology, high energy consumption and high pollution. This decision urged enterprises to introduce energy-saving and emission-reducing technologies. In 2000, the State Council launched the "West to East Gas Transmission" project. This project promoted the adjustment of China's energy structure and turned the resource advantage of the Western region into a source for economic growth. In 2009, Premier Wen pledged at the Copenhagen conference that China's carbon dioxide emissions would be 40% to 45% lower by 2020 than in 2005 (Li et al., 2018). Thereafter, new changes occurred in China's energy supply and demand situation, and the pace of industrialisation and urbanisation accelerated. In recent years, some high energy-consuming industries have developed rapidly, leading to a gradual increase in total energy production. In 2017, the "One Belt, One Road" energy cooperation project strengthened international exchanges with a focus on energy, leading China to play a greater role in the global energy governance system.

When using the SBM-DEA model to calculate energy efficiency, we must set input-output indicators (Rashidi et al., 2015). Input indicators are divided into energy and non-energy inputs. The total energy consumption in various regions is considered the energy input, which includes 8 types of energy, such as coal, coke and natural gas (Shao et al., 2011). Non-energy inputs include capital stock and labour. We adopt the perpetual inventory method to calculate capital stock (Shan, 2008). Labour input is measured by the employment population (Chen et al., 2016). Output indicators are divided into desirable and undesirable outputs. Provincial GDP is used as the desirable output variable. In the process of energy consumption, pollutants, such as carbon dioxide, nitrogen oxides and sulphides, are discharged (Lu et al., 2014; Suzuki & Nijkam, 2016). Among them, carbon emissions constitute the factor with the greatest impact on climate and the environment (Korhonen & Snäkin, 2015). Therefore, we use CO_2 emissions as an undesirable output in the process of energy consumption, and the calculation method is based on Shan et al. [www.nature.com/scientificdata][3]. In the process of using SBM-DEA to calculate energy efficiency, the pure technical efficiency (PTE) score and the technical efficiency (TE) score are exported at the same time. Table 1 shows the TE score as a reflection of China's energy efficiency (EE), which is divided into the Eastern, Central and Western regions[4]. Hainan, Beijing, Ningxia and Qinghai have energy efficiency values of greater than 1, indicating that they are high efficiency areas that fully utilise their energy resources and constitute the frontier of energy efficiency. They achieve the same output with a minimum energy input, and the room for energy conservation and emissions reduction is relatively small, but the pressure for energy conservation and emissions reduction is very large. Beijing, Liaoning, Zhejiang, Jiangsu, Guangdong, Hebei, Shandong, Heilongjiang, Shanxi, Jiangxi, Hubei, Hunan, Henan, Chongqing, Gansu, Shaanxi and Guizhou present improvements in energy efficiency. Jilin, Inner Mongolia, Guangxi, Ningxia, Qinghai, Xinjiang and Yunnan present almost equal values. The values of Hainan, Tianjin, Shanghai, Fujian and Anhui have gradually decreased; most of these areas are distributed in the Eastern region. The reason for their decreasing values is that, in some large cities, such as Guangdong and Shanghai, population expansion,

Table 1. Results and ranking of energy efficiency.

province	1997	2000	2003	2006	2009	2012	2015	2017	rank	trend
Eastern Region										
Hainan	1.421	1.416	1.316	1.302	1.289	1.279	1.226	1.200	1	↓
Beijing	1.048	1.139	1.212	1.068	1.065	1.053	1.091	1.127	2	↑
Tianjin	1.071	1.059	1.059	1.102	1.024	0.558	0.447	0.421	5	↓
Shanghai	1.026	0.719	0.602	0.579	0.619	0.624	0.588	0.617	6	↓
Fujian	0.202	0.185	0.173	0.163	0.164	0.159	0.167	0.173	10	↓
Liaoning	0.134	0.141	0.141	0.133	0.134	0.139	0.163	0.179	14	↑
Zhejiang	0.133	0.123	0.124	0.119	0.121	0.131	0.146	0.153	16	↑
Jiangsu	0.075	0.074	0.075	0.076	0.081	0.087	0.101	0.133	22	↑
Guangdong	0.097	0.082	0.079	0.074	0.072	0.069	0.077	0.070	25	↑
Hebei	0.063	0.061	0.062	0.065	0.069	0.069	0.071	0.074	27	↑
Shandong	0.056	0.053	0.051	0.052	0.054	0.053	0.059	0.064	28	↑
Total	0.423									
Central region										
Jilin	0.182	0.204	0.204	0.198	0.192	0.195	0.217	0.215	8	→
Inner Mongolia	0.192	0.207	0.200	0.178	0.180	0.164	0.155	0.149	9	→
Heilongjiang	0.146	0.148	0.150	0.155	0.149	0.155	0.166	0.172	13	↑
Shanxi	0.127	0.131	0.135	0.135	0.143	0.137	0.136	0.140	15	↑
Jiangxi	0.109	0.115	0.109	0.114	0.118	0.128	0.137	0.148	18	↑
Guangxi	0.099	0.094	0.092	0.097	0.092	0.096	0.106	0.109	20	→
Hubei	0.062	0.067	0.069	0.075	0.086	0.092	0.106	0.110	23	↑
Hunan	0.072	0.077	0.071	0.077	0.082	0.083	0.095	1.200	24	↑
Anhui	0.062	0.066	0.072	0.076	0.082	0.089	0.093	0.099	26	↓
Henan	0.046	0.044	0.043	0.048	0.048	0.047	0.051	0.058	30	↑
Total	0.132									
Western region										
Ningxia	1.077	1.062	1.052	1.020	1.029	1.032	1.046	1.064	3	→
Qinghai	1.052	1.048	0.608	1.007	1.046	1.065	1.039	1.054	4	→
Xinjiang	0.243	0.262	0.262	0.260	0.258	0.265	0.225	0.215	7	→
Chongqing	0.154	0.167	0.177	0.167	0.172	0.171	0.190	0.205	11	↑
Gansu	0.146	0.156	0.151	0.162	0.167	0.179	0.178	0.171	12	↑
Shaanxi	0.103	0.114	0.112	0.123	0.128	0.136	0.141	0.147	17	↑
Yunnan	0.094	0.095	0.094	0.096	0.104	0.099	0.106	0.109	19	→
Guizhou	0.079	0.077	0.071	0.083	0.103	0.113	0.128	0.136	21	↑
Sichuan	0.047	0.049	0.048	0.051	0.055	0.059	0.066	0.071	29	→
Total	0.334									

Note: Total represents the energy efficiency of the Eastern, Central and Western regions; Rank represents the efficiency ranking in 30 provinces; ↑, →, ↓ represent the rise, equal and decline of energy efficiency respectively.
Source: Authors.

traffic congestion and haze are gradually emerging, leading to environmental degradation and decreased energy efficiency.

The economy is stronger in the Eastern region than in the Central and Western regions. In the process of energy consumption, advanced technologies are used to reduce the emission of pollutants, so energy efficiency takes a leading position. Zhou et al. (2020) also confirmed that the energy efficiency in China shows a clear geographical step distribution, and the Eastern region has the highest efficiency. This advantage is reflected in the rankings of provisional energy efficiency; Hainan and Beijing are the top two in the Eastern region. Hainan is committed to building an international tourism island, and the key aims are to “maintain ecological balance and save energy resources". As discussed in the pollution haven hypothesis (Ulph, 1996), some polluting industries in developed cities could be transferred to developing areas. Since 2000, Beijing has transferred a large number of energy-intensive, high-pollution, low-revenue secondary industries into Hebei Province, while some enterprises have been simply shut down. This initiative has caused Hebei to become the most polluted area in China; therefore, it ranks 27th in energy efficiency. Since

1999, China has implemented the policy of developing the Western region, and the strategy of "West to East Gas Transmission" will inevitably have an impact on the energy efficiency of the Western region. The efficiency gap between the Western and Eastern regions is only 0.089[5], and Ningxia and Qinghai rank third and fourth, respectively. Ningxia, Qinghai, Xinjiang and Gansu still have many existing energy resources, especially coal, oil and natural gas. The proven reserves of oil and natural gas in the Western region account for 41% and 65% of the national total, respectively. The energy efficiency of the Central region is 0.132, which is the lowest of the Eastern, Central and Western regions, and Guangxi, Hubei, Hunan, Anhui and Henan in the Central region rank in the last 10. These areas do not have abundant resources like provinces in the Western region do, and because they are located inland, inconvenient transportation causes their economic development to lag far behind that of coastal cities. Yuan et al. (2019) also proved that the level of financial agglomeration and green development in the Eastern and Western areas is higher than that in the Central areas, showing a clear trend of spatial convergence.

We take energy efficiency as a dependent variable, and its influencing factors are divided into institutional and economic factors. Fiscal decentralisation is defined as the proportion of provincial and central budget expenditures (Fiva, 2006; Jin & Zou, 2002; Zhang & Zou, 1998), and we measure the level of decentralisation by comparing the expenditures and revenues of the central and super-ordinate provincial governments. With the increase in the proportion, the relationship between the central and local governments becomes more distant, and the degree of fiscal decentralisation increases (Zhang, 2006). Economic factors are expressed by the upgrading of industrial structures. According to Petty Clark's law[6], secondary industry first gradually replaces primary industry as the main driving force of economic development, and tertiary industry comes to take prominence. Energy efficiency can be improved by reducing the high energy consumption of the secondary industry (Chen et al., 2019). This paper uses the ratio of the output value of the tertiary industry to the output value of the secondary industry to indicate the upgrading of the industrial structure.

This study adopts five control variables that play important roles in China's energy efficiency. Population density plays an important role in energy consumption in developing countries, in which frequent human activities are main driving factors of energy consumption. Population density is obtained by the ratio of population to area. The degree of opening to the outside world is a necessary means to promote economic development (Tiwari et al., 2013), and it is measured by the ratio of total import and export volume to added value. The proportion of secondary industry reflects the level of industrialisation, and its rapid development affects energy efficiency (Wu et al., 2005). Moreover, the innovation ability of industry cannot be ignored, and energy input and consumption can be reduced through innovation. R&D expenditure represents industrial innovation (Yu et al., 2016). GDP represents the level of economic development, and developed regions pay more attention to energy efficiency than developing regions (Jalil & Feridun, 2011). The real GDP per capita of each province is selected and deflated based on the 1997 price level (Ang, 2009; Halicioglu, 2009; King & Levine, 1993).

Table 2. Influencing factors of energy efficiency.

	Equation (6)	Equation (8)	Equation (9)
γ_{01} / α_1	–	−0.079***	−0.209***
c_1 /γ_{10} /α_2	0.024	−0.153***	−0.095
γ_{11} /α_3	–	0.112***	0.111***
α_4	0.038 ***	0.049***	0.069***
α_5	−0.383***	−0.419***	−0.605***
α_6	−0.877***	−0.772***	−1.001***
α_7	−0.036***	−0.028***	−0.092***
α_8	0.069	−0.494	−2.537***
C	−0.363	0.613	–
β_1	–	–	0.243**
β_2	–	–	0.103
β_3	–	–	0.017
β_4	–	–	0.019
β_5	–	–	0.691***
β_6	–	–	−0.102
β_7	–	–	0.063
β_8	–	–	10.004***
ρ	–	–	−0.565***
Adj R^2	0.589	0.613	–
F	577.240***	590.000***	–

Note: 1. **, *** respectively represent the significance levels of 5%, 1%.
2. $\alpha_4,\alpha_5,\alpha_6,\alpha_7,\alpha_8$ represent the elastic coefficient of Trade Openness; Industrialisation, Population Density, Research and Development (R&D), GDP.
3. β_4, $\beta5$, $\beta6$, $\beta7$, $\beta8$ represent the elastic coefficient of $\sum w_{ij}control_{jt}{}^{jt}$, controls represent Trade Openness; Industrialisation, Population Density, Research and Development (R&D), GDP.
Source: Authors.

6. Empirical results

6.1. Spatial regression results

Moran's I index is selected as the index to measure spatial autocorrelation (Moran, 1950), and the test indicates that the spatial dependence of EE in all regions has been stable and intensified, as shown in Appendix II. Table 2 shows the fixed effect estimation results of different interpreted variables, among which Equation (5) and Equation (7) are OLS estimations, and Equation (8) is a maximum likelihood estimation (MLE) (Anselin, 1988; Elhorst, 2014).

Equation (5) shows the effect of the IS on EE. The elasticity coefficient c_1 is 0.024, which is not significant at the 10% level. The coefficients of γ_{01} and γ_{10} are −0.079 and −0.153, respectively, and FD and IS have no impact on the improvement in EE. The coefficient of γ_{11} is 0.112, which is significant at the 1% level and verifies the regulatory role of FD. The direction of the elasticity coefficient of each variable in the SDM is similar to that in the OLS. The SDM is robust, and we can use it to study the factors influencing EE.

From the results of Equation (8), the impact of FD on EE is significantly negative, and the elasticity coefficient α_1 is −0.209. Fiscal decentralisation gives local governments' greater autonomy (Oates and Schwab, 1996). To pursue maximum profits, local governments ignore environmental pollution in the process of energy consumption. The behaviour of pursuing economic growth at the expense of the environment is contrary to the purpose of fiscal decentralisation (Zhang, 2020). Mohamed et al. (2020) also attested that a certain degree of fiscal decentralisation can negatively affect the energy sector. The influence of IS on EE is negative, and the elasticity coefficient α_2 is −0.095, although it is not significant. Shi and Zhang (2003) found that the influence of changes in the industrial structure on energy efficiency has gradually decreased since the mid-1990s. China's industrialisation process has been relatively underdeveloped, and the economic development in many cities remains driven by secondary industries, which have high energy consumption and pollution emissions (Zhou et al., 2018). In addition, the tertiary industry is experiencing rapid development, and its producer services and modern services for carbon emissions are not clear. Shi and Ma (2014) found that the impact of industrial structures on energy efficiency depends on two effects: the promotion of efficiency within the industry and the improvement in the inter-industry structure. The interaction term of FD and IS is significantly positive, and the elasticity coefficient α_3 is 0.111. If the incentives offered by the government are reasonable, fiscal decentralisation will produce technological progress, innovation spillover and competition effects. Local governments will focus their limited funds on industries that can produce economic benefits in a short period of time, usually energy- and emission-intensive industries. Only when the local fiscal expenditures reach a certain level will local governments consider improving energy efficiency while pursuing economic development. China seeks to steadily improve energy efficiency in the future, and this plan depends to a large extent on whether fiscal decentralisation regulates the energy-saving and emission-reducing effects of the industrial structure well (Cheng et al., 2020). Under the fiscal tax sharing system, this outcome is also related to the local government's ability to perform resource allocation.

Most control variables show the expected signs and are statistically significant. From the results of Equation (8), for control variables such as trade openness, industrialisation, population density, R&D and GDP, the corresponding estimated values are 0.069, −0.605, −1.001, −0.092 and −2.537, respectively, and all are significant at the 1% level. First, enterprises introduce advanced clean technology, environmental protection facilities and management experience through trade openness. Through a reasonable division of labour, enterprises can improve the regional environmental quality in cooperation with local governments and alleviate the vicious circle of high energy consumption, high emissions and high pollution. Second, it is undeniable that China's economic growth is mainly driven by the process of emerging industrialisation, and the acceleration of capital formation is closely related to sustained industrialisation. However, industrial development has also discharged a large amount of environmental pollutants, and energy savings and emissions reduction have become urgent (Tang et al., 2016). Third, the density of China's population has been increasing, and the large population renders environmental pollution more likely. Hao and Liu (2016) found that population density is the main cause of haze and that an increase in population density has a negative impact on energy efficiency. Fourth, in China, the R&D investment of industrial enterprises accounts for approximately 0.9% of sales revenue, while the average proportion in developed countries is 2%. Due to the lack of R&D investment, in the process of energy consumption, the output cannot reach the ideal expectations, preventing improvement in energy efficiency. Finally, GDP has a negative effect on EE. In many regions of China, governments remain committed to economic development, and they choose to sacrifice the environment to obtain more income and ignore pollution in the process of energy consumption (Akram et al., 2020; Destek & Sarkodie, 2019; Usama et al., 2015; Zhang et al., 2017).

Table 3. Effect decomposition of SDM.

	Direct effect	Indirect effect	Total effect
β_1	−0.112***	0.134***	0.023
β_2	−0.055	0.059	0.005
β_3	0.101***	−0.018	0.082*
β_4	0.064***	−0.008	0.056***
β_5	−0.328***	−0.382***	0.054
β_6	−0.874***	0.171	−0.703***
β_7	−0.061***	0.043***	−0.018***
β_8	0.522	4.282***	4.803***

Note: *** respectively represent the significance levels of 1%.
Source: Authors.

Table 4. Influencing factors of energy efficiency: Eastern, Central, Western region.

	Eastern	Central	Western
α_1	−0.508***	−0.509***	0.269
α_2	−0.466**	−0.931**	−0.237
α_3	0.249**	0.364*	−0.019
β_1	0.448**	0.241*	−0.480*
β_2	0.648***	1.657**	1.455**
β_3	−0.308*	−0.613*	−0.858**
ρ	−0.148***	−0.935***	−1.426***
Adj R^2	0.751	0.754	0.721

Note: *, **, *** respectively represent the significance levels of 10%, 5% and 1%.
Source: Authors.

Table 3 shows the direct, indirect and total effects of Equation (8) in the SDM. The direct effect refers to the impact of various factors on the EE in local areas, and the results are similar to those in Table 3. Considering that the waste of resources or environmental pollution can easily cross administrative boundaries, the indirect effect reflects that energy governance has high spatial externality. Regarding the indirect effect of FD on EE, the result shows a positive correlation at the 1% significance level, and the elasticity coefficient β_1 is 0.134. Economically developed areas have a high ability to attract investment, and the positive external effects can radiate to neighbouring regions, which can use the advanced technology from the developed areas to drive economic development (Hu et al., 2020). For example, Beijing transfers industry with advanced technology to the surrounding areas. In exchange for increased revenue, local governments facing fiscal pressure are willing to take over these enterprises (Que et al., 2018). The spill-over effect can greatly increase output and improve energy efficiency.

Table 4 shows the MLE results of the Eastern, Central and Western regions. The three regions present significant differences in aspects such as geographic position, economic strength, energy reserves and technical level, affecting the changes in EE. In the Eastern region, FD can improve energy technical efficiency by affecting the IS, with a significant elasticity coefficient α_3 of 0.249 at the 5% level. Compared with the single adjustment range of the IS, FD could play a stronger role in promoting the upgrading of the industrial structure. The main reason for this development is that people in the Eastern areas pay more attention to environmental quality than people in other regions, prompting the government to make stricter regulations on high pollution and energy-intensive enterprises. The spill-over effect of FD in the Eastern region is the largest – at least at the 10% significance level. The elasticity coefficient of β_1 is 0.448, while the β_1 in the Central and Western regions is 0.241 and −0.480, respectively. The Eastern coastal areas, relying on geographical advantages, were the first selected to implement the reform and opening-up policy in 1978, and they have gradually become the advanced driving force of China's economy. Similarly, the spillover effect of the IS has a significant positive impact on EE, and the elasticity coefficient of β_2 is 0.648. The upgrading of industrial structures can promote the development of industrialisation and urbanisation. In the long term, the scale economy in the market will improve energy efficiency across the whole region.

In the Central region, EE is negatively correlated with FD and IS. The elasticity coefficients of α_1 and α_2 are -0.509 and -0.931, respectively, and they are both significant at the 1% level. However, FD can have a significantly positive effect on EE by upgrading the industrial structure, with an elasticity coefficient of α_3 of 0.364. It is worth mentioning that FD has the greatest impact on EE in the Central region. This phenomenon can be attributed to the major national strategies for the Central region, namely, "the Rise of Central China[7]" and "The Belt and Road (B&R)"[8] The purpose of these policies is to narrow the gap in economic development between the inland and Eastern coastal areas and to promote the active cooperation of the Eastern, Central and Western regions. When undertaking industrial transfer from the Eastern region, the Central region constantly optimises its own industrial structure. The results for the Eastern and Central regions are consistent with environmental federalism (Oates & Schwab, 1996), and fiscal decentralisation affects environmental quality and energy efficiency through the allocation of economic factors.

In contrast, in the Western region, the effect does not meet expectations, and the results are not significant. Cities in the West are situated in the deep inland area of China and have an unsuitable climate and inadequate transportation systems, and their socio-economic development has long lagged behind that of other areas (Shen et al., 2020). Although the Western region has abundant resources, and China implemented the strategy of "Great Western Development[9]" in 2001, it must still be further strengthened in terms of policies and industries. Therefore, reflected in the production function, the Western region has insufficient capital investment and an unreasonable industrial structure, and the economic output of energy consumption cannot achieve the expected effect. Bevan (2003) noted that developing regions that are unusually well endowed with natural resources often seem to derive little benefit from their apparent good fortune. Cheng et al. (2020) indicated that the implementation of local energy-saving and emissions-reducing policies might not achieve the desired effect, especially in developing regions. These areas tend to neglect the emissions reduction targets set by the central government.

6.2. Robustness testing

In the process of using SBM-DEA to estimate energy efficiency, we obtain the PTE score and the TE score at the same time. There is also another efficiency evaluation index called Scale Efficiency (SE), which is the ratio of TE to PTE. Therefore, to further enhance the robustness of the empirical results, we use PTE and SE as indicators to reflect China's energy efficiency during 1997-2017. We calculate Moran's I of PTE

Table 5. Regression results of robustness test.

	PTE model	SE model
α_1	−0.230*	0.035
α_2	0.005	−0.056
α_3	0.026**	0.028*
α_4	0.114***	−0.052
α_5	−0.369***	−0.082
α_6	−0.680**	−0.183
α_7	−0.082**	0.010
α_8	1.079***	−0.079
β_1	0.435***	−0.182*
β_2	−0.099	−0.004
β_3	−0.006	0.068
β_4	−0.180***	0.123*
β_5	0.459***	−0.094
β_6	0.696	−0.171
β_7	0.072**	−0.009
β_8	−1.524***	0.596***
ρ	0.703***	0.737***

Note: *, **, *** respectively represent the significance levels of 10%, 5% and 1%.
Source: Authors.

and SE, and the results show that they are positive at the 1% significance level. It is appropriate to carry out MLE through SDM, and the results are shown in Table 5.

When we change the measure of energy efficiency from EE to SE or PTE, the empirical results in Table 5 are basically consistent with those in Table 2, and only the coefficient and its significance are reduced or improved to a certain extent. However, this fact still does not affect the conclusions of this paper. The interaction term of FD and IS is positive at least at the 10% significance level, further indicating that the upgrading of industrial structures can improve China's energy efficiency under fiscal decentralisation.

7. Conclusion and policy implications

This study examines the relationships among fiscal decentralisation, industrial structure and energy efficiency in China using the SDM approach. The primary findings are as follows. Energy efficiency shows a clear geographical step distribution (Zhou et al., 2020). The economy is stronger in the Eastern region than in the Central and Western regions, so the Eastern region holds a leading position. However, the energy efficiency of the Central region is lower than that of the Eastern and Western regions. Because they are located inland, inconvenient transportation causes their economic development to lag far behind that of coastal cities.

Fiscal decentralisation has a positive effect on the energy efficiency of the Eastern and Central regions by upgrading the industrial structures. The main reason for this development is that people in the Eastern areas pay more attention to environmental quality than people in other regions, prompting the government to more strictly regulate high pollution and energy-intensive enterprises. The results are also in line with environmental federalism theory (Oates & Schwab, 1996): through the allocation and transfer of industrial factors, fiscal decentralisation affects energy governance. The Western region has abundant resources, so its energy efficiency ranks at an average level. However, the impact of fiscal decentralisation or industrial structures is not significant. It is difficult for advanced technology to be introduced into the Western region due to its remote geographical location. In addition, under the guidance of fiscal decentralisation, the government's policies have positive externalities on the local and surrounding areas, promoting the protection of the environment and the conservation of energy across the whole region.

These results could be useful for governments seeking to improve energy efficiency. The years 2020 and 2030 are important dates for the Chinese government to fulfil its commitments to the international community concerning emissions reductions. Fiscal decentralisation has a negative impact on improving local energy efficiency. In fact, fiscal decentralisation gives local governments' greater autonomy (Oates and Schwab, 1996). To pursue maximum profits, local governments ignore environmental pollution in the process of energy consumption, in contrast to the purpose of fiscal decentralisation (Zhang et al., 2020). On the one hand, the central government should adhere to appropriate decentralisation and grasp the allocation of financial power between the central and local governments (Jia et al., 2014). On the other hand, it is very important for it to strengthen the management and supervision of budget funds. The conclusion also shows that the implementation effects of fiscal decentralisation in the Eastern, Central and Western regions are different. Local governments should fully expand the advantages of local resources, spatial location and policy environment to formulate policies to improve energy efficiency. One point to be noted is that the effect of fiscal decentralisation is more significant in geographically connected regions, indicating that, in respect of energy management, jurisdictional cooperation is of great significance. In light of the geographical step distribution of energy efficiency, local governments should formulate policies and targets to improve energy efficiency according to regions' different development levels (Liu et al., 2020). Further, the Central and Western areas, which have greater space for improvement and present lower energy efficiency, should receive attention to balance the regional differences. It is worth noting that the upgrading of industrial structures has no significant effect on energy efficiency. Against the background of fiscal decentralisation, local governments consider the upgrading of industrial structures as the intermediate goal and regulation direction and finally achieve the dual goal of economic growth and energy efficiency improvement.

Notes

1. Data Source: U.S. Energy Information Administration (https://www.eia.gov/)
2. Primary industries: agriculture, forestry, animal husbandry, fishery, *etc.*; secondary industries: manufacturing, construction, public engineering, pharmaceutical manufacturing, *etc.*; and tertiary industries: commerce, finance, transportation, communication, education, service industry, *etc.*
3. www.nature.com/scientificdata
4. Eastern region: Liaoning, Beijing, Tianjin, Shanghai, Hebei, Shandong, Jiangsu, Zhejiang, Fujian, Guangdong, Guangxi, and Hainan; Central region: Heilongjiang, Jilin, Shanxi, Inner Mongolia, Anhui, Henan, Hubei, Hunan, and Jiangxi; and Western region: Chongqing, Sichuan, Yunnan, Guizhou, Tibet, Shaanxi, Gansu, Qinghai, Ningxia
5. Energy efficiency in the east-Energy efficiency in the west = 0.423-0.334 = 0.089.
6. In 1940, Colin Clark introduced a theory of industrial structure based on William Petty's research.

7. A policy to promote the common rise of six provinces (Shanxi, Anhui, Jiangxi, Henan, Hubei, Hunan) in Central China
8. The policy promotes the connections among 18 provinces in China (Xinjiang, Chongqing, Shaanxi, Gansu, Ningxia, Qinghai, Inner Mongolia, Heilongjiang, Jilin, Liaoning, Guangxi, Yunnan, Tibet, Shanghai, Fujian, Guangdong, Zhejiang and Hainan).
9. The policy aims to expedite the economic construction of the Western region and realize regional common prosperity.

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Appendix A: The SBM-DEA model

Tone (2002) further develops a super efficiency SBM-DEA model that allows the efficiency score to be greater than 1 and can easily rank efficient decision-making units (DMU*s*). Assume that each DMU$_k$ uses m inputs x_{ik} ($i = 1, 2\ldots, m$) to produce not only r_1 desirable outputs y_{jk} ($j = 1, 2\ldots, r_1$) but also r_2 undesirable outputs b_{jk} ($j = 1, 2\ldots, r_2$). Then, Equation (5) can be used for the efficiency evaluation of DMU*s* with undesirable outputs.

$$\min \rho_k = \frac{1/m\left(\sum_{i=1}^{m} s_i^x / x_{ik}\right)}{1/(r_1 + r_2)\left(\sum_{j=1}^{r_1} s_j^y / y_{jk} + \sum_{j=1}^{r_2} s_j^b / b_{jk}\right)} \tag{5}$$

$$s.t.\quad \sum_{l=1,\; l\neq k}^{n} \lambda_l x_{il} + s_i^x = x_{ik} \quad (i = 1, 2, \ldots, m)$$

$$\sum {}_{l \neq k}^{l=1}{}^{n} \lambda_l y_{jl} - s_j^y = y_{jk} \quad (j = 1, 2, \ldots, r_1)$$

$$\sum {}_{j \neq k}^{l=1}{}^{n} \lambda_l b_{jl} + s_j^b = b_{jk} \quad (j = 1, 2, \ldots, r_2)$$

$$\lambda_l \geq 0 \quad (l = 1, 2, \ldots n)$$

$$s_i^x \geq 0 \quad (i = 1, 2, \ldots, m)$$

$$s_j^y \geq 0 \quad (j = 1, 2, \ldots, r_1)$$

$$s_j^b \geq 0 \quad (j = 1, 2, \ldots, r_2)$$

In Equation (5),s^x, s^y ands^b are slacks corresponding to inputs, desirable outputs and undesirable outputs of the DMUs, respectively. r_2 and r_2 denote the number of desirable outputs and undesirable outputs, respectively. The slacks of the DMU*s* are used in the objective function to measure the efficiency of the DMU*s*, where a value of 1 means that a DMU_k is efficient. Inefficient DMUs can be improved by reducing (increasing) all inputs (outputs) in equal proportions. Equation (5) has the super efficiency property, which allows us to rank every DMU by adding the constraint $l \neq k$ and changing the structure of the objective function (Chu et al., 2018). Undesirable outputs are also added and treated differently from desirable outputs, so we can evaluate efficiency by taking CO_2 emissions into consideration (Nejat et al., 2015).

Appendix B: Spatial autocorrelation test

Year	Moran's I	Year	Moran's I
1997	0.400***	2008	0.420***
1998	0.402***	2009	0.414***
1999	0.403***	2010	0.426***
2000	0.422***	2011	0.426***
2001	0.421***	2012	0.431***
2002	0.418***	2013	0.433***
2003	0.432***	2014	0.440***
2004	0.435***	2015	0.428***
2005	0.432***	2016	0.420***
2006	0.423***	2017	0.414***
2007	0.421***	–	–

Note: *** respectively represent the significance levels of 1%.
Source: Authors.