Measurement and Spatial Evolution of Regional Energy Efficiency in China

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Abstract. Energy is an important factor of production to ensure sustainable development of country. There are obvious regional differences in energy efficiency in China at the present stage. In this context, this paper studies the provincial energy efficiency in China. Under the framework of total factor energy efficiency analysis, the total factor energy efficiency of 30 provinces (cities and autonomous regions) in China from 2007 to 2016 is measured by means of the global super-efficiency SBM-DEA model. Further, this article is based on the space perspective, with the aid of spatial econometric theory and methods, to the Chinese provincial total factor spatial correlation of the energy efficiency test, the results show that there are provincial total factor of energy efficiency in the space since the correlation of the regional difference of China's total factor energy efficiency analysis and put forward the corresponding countermeasures.

1. Introduction
As an indispensable factor of production in the process of economic production, energy plays an important role in supporting the survival and development of human society and the stable growth of economy. However, China's current energy situation is not optimistic. After China's 13th five-year plan puts forward the concept of innovative, coordinated, green, open and Shared development, China will pay more attention to green development and make continuous efforts to achieve sustainable development.

In view of the importance of energy in China's economic production, many scholars have carried out research and analysis on it, mainly including single factor and total factor energy efficiency. In terms of single-factor energy efficiency, Neng [1] analyzed the relationship between energy efficiency and government intervention, industrial structure, energy consumption and other variables based on the calculation results of single-factor energy efficiency. Huang [2], Zhang [3] measured the changes of energy efficiency in China in different periods based on the single factor energy efficiency method. Han Zhiyong et al. [4] estimated China's industrial energy efficiency from 1998 to 2000, and analyzed the change of China's energy intensity during this period. Although single factor energy efficiency is widely used, many studies have found that single factor energy efficiency has many defects. For example, Jenne and Cattell [5] believe that there are significant energy efficiency differences among different industries, and the single factor energy efficiency index cannot reflect such differences. Wilson [6] believes that the energy efficiency of a single factor cannot reflect the impact of technical factors on energy efficiency. Ghali et al. [7] believes that the energy efficiency of a single factor can only measure the ratio between input and output, and cannot measure the substitution relationship between energy input and other input.
factors (such as capital, labor, raw materials, etc.). In terms of total factor research, total factor of energy efficiency to the total factor productivity method in economics, the energy as a kind of inputs, inspects its economic output, measure the situation of energy use, this concept was first made by Hu and Wang [8], they are based on the total factor productivity framework, using DEA method defines the total factor of energy efficiency indicators (TFEE), makes up for the traditional indicators of energy productivity only considering the defects of the energy of a single element. DEA method is commonly used in the measurement and research of labor productivity, and it can also be used in the measurement and research of energy efficiency after development. Li Shixiang [9] believes that total factor energy efficiency method is a good analytical framework for evaluating energy efficiency. Some scholars have used DEA method to analyze the energy efficiency and energy-saving potential of industrial sectors or sectors in different countries in the world. Hu and Kao [10] constructed a method model to calculate the energy saving rate under the framework of total factor energy efficiency using DEA method. Honma and Hu [11] used four input factors: capital stock, labor, energy and non-energy intermediate input, and measured Japan's total factor energy efficiency with DEA method. In the framework of single factor energy productivity, only energy input and economic output in the production process are considered, while in the framework of total factor energy productivity, not only energy input but also other production factors such as capital and labor are considered. Using DEA method to measure total factor energy efficiency has been practiced and recognized by many scholars at home and abroad.

To sum up, based on the realistic background, combined with China's current economic development in the new normal, to regional energy efficiency measures as the breakthrough point, first determine the input and output indicators, SBM - super efficiency DEA model is used to measure the regional total factor of energy efficiency, and then based on the spatial perspective analysis of regional total factor space evolution process of energy efficiency, suggestion is given.

2. Models Establishment

2.1. Super-efficient SBM-DEA model

Compared with the general data envelopment method, the advantages of the super-efficiency SBM-DEA model are mainly as follows: Firstly, the efficiency measurement process not only includes the proportion of input and output to reduce or increase, but also includes the slack variable of input and output, which is more in line with the reality of economic production. Secondly the efficiency obtained is not limited to within 1, but can be greater than 1, which is helpful to further distinguish the efficiency value of effective DMU. Based on these two points, SBM super-efficiency model is selected in this paper to measure regional energy efficiency. The specific model formula is as follows:

$$
\begin{align*}
\min p_{SE} &= \frac{1}{m} \sum_{i=1}^{m} x_i / \bar{x}_{ik} \\
&\quad + \frac{1}{s} \sum_{r=1}^{s} y_r / y_{rk} \\
\text{s.t. } \bar{x}_i &\geq \sum_{j=1,j \neq k}^{n} x_{ij} \lambda_j \\
\bar{x}_i &\geq x_{ik} \\
\bar{y}_r &\geq y_{rk} \\
\lambda, s^-, s^+, \bar{y} &\geq 0 \\
i = 1, 2, \ldots, m, r = 1, 2, \ldots, q, j = 1, 2, \ldots, n (j \neq k)
\end{align*}
$$
2.2. **Spatial correlation analysis**

2.2.1. **Global spatial correlation analysis.** Measuring the **Moran’s I** reflect energy efficiency across the country showed the average degree of correlation. With Moran’s I value in $[1, 1]$, I said is greater than 0, is equal to 0 means not related, is less than 0 means negative correlation, while the closer to 1 indicates that the value of science and technology financial ecosystem development degree is higher (or lower) provinces on the space agglomeration significantly. Moran’s I calculation formula is as follows, including $Z_a$, $Z_b$ is $a, b$ province energy efficiency value $(a, b \in \{1, 2, \cdots, n\})$, $w$ using weighted space adjacent matrix.

$$
\text{Moran's } I = \frac{\sum_{a=1}^{c}\sum_{b=1}^{c}(Z_a - \overline{Z})(Z_b - \overline{Z})}{S^2 \sum_{a=1}^{c}\sum_{b=1}^{c}w_{ab}}
$$

2.2.2. **Local spatial correlation analysis.** Moran's I can reflect the status of spatial agglomeration, but can't determine the specific space gathering area. Therefore, this paper further describes it in the form of Moran scatter diagram. Among them, the first I quadrant (gather) on behalf of the energy efficiency higher provinces gathered to provincial strong spatial correlation and differences between the low level; The first II quadrant (hollow) on behalf of the provincial energy efficiency is relatively low development level is higher, but the surrounding areas between provincial strong heterogeneity and difference degree; The first III quadrant (depression) on behalf of the province together with lower energy efficiency, provincial strong spatial correlation and differences between low level; The first IV quadrant (island) on behalf of the energy efficiency higher development level is low, but the surrounding areas between provincial strong heterogeneity and difference degree is bigger.

3. **Empirical analysis**

3.1. **Input-output index description**

Tibet regional energy consumption data, missing data do not have to Hong Kong, Macao and Taiwan regions, therefore this chapter is based on China's 30 provinces and cities in 2007-2016 panel data of Chinese provincial level to calculate total factor efficiency, input key selection process necessary capital input, labor input and energy input, output as real GDP. This chapter refers to the "perpetual inventory method" proposed by Jun et al. [12] to estimate the actual capital stock of each province from 2007 to 2016. In this paper, the energy consumption converted into standard coal in each province and city is used as the measurement index of energy input. The unit is 10,000 tons of standard coal. The output index is measured by the actual GDP in the base period of 2007, which is 100 million yuan. The data were obtained from the national bureau of statistics, China statistical yearbook, China energy statistical yearbook, etc.

3.2. **Energy efficiency measurement results**

With the help of MYDEA software, according to the above input-output data, the global super-efficiency SBM-DEA model is used to measure the energy efficiency of 30 provinces in China. The measurement results are shown in table 1:
Table 1. Calculation results of total factor energy efficiency

| Area  | 2007  | 2008  | 2009  | 2010  | 2011  | 2012  | 2013  | 2015  | 2016  |
|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
| Beijing | 0.707 | 0.728 | 0.763 | 0.794 | 0.829 | 0.855 | 0.882 | 0.901 | 0.959 | 1.028 |
| Tianjin | 0.730 | 0.721 | 0.697 | 0.713 | 0.720 | 0.729 | 0.739 | 0.756 | 0.804 | 0.829 |
| Hebei   | 0.540 | 0.536 | 0.527 | 0.501 | 0.489 | 0.490 | 0.487 | 0.488 | 0.494 | 0.500 |
| Shanxi  | 0.527 | 0.501 | 0.487 | 0.458 | 0.419 | 0.414 | 0.409 | 0.406 | 0.405 | 0.398 |
| Nei Mongol | 0.539 | 0.486 | 0.471 | 0.468 | 0.462 | 0.461 | 0.462 | 0.462 | 0.469 | 0.472 |
| Liaoning | 0.601 | 0.556 | 0.531 | 0.526 | 0.527 | 0.533 | 0.537 | 0.540 | 0.562 | 0.565 |
| Jilin   | 0.567 | 0.512 | 0.484 | 0.467 | 0.464 | 0.467 | 0.479 | 0.499 | 0.528 | 0.541 |
| Heilongjiang | 0.623 | 0.633 | 0.633 | 0.631 | 0.610 | 0.595 | 0.595 | 0.592 | 0.605 | 0.600 |
| Shanghai | 0.750 | 0.755 | 0.801 | 0.812 | 0.833 | 0.862 | 0.905 | 0.945 | 1.020 | 1.009 |
| Jiangsu | 0.706 | 0.711 | 0.730 | 0.742 | 0.731 | 0.723 | 0.738 | 0.758 | 0.793 | 0.826 |
| Zhejiang | 0.666 | 0.663 | 0.678 | 0.685 | 0.682 | 0.698 | 0.710 | 0.730 | 0.749 | 0.776 |
| Anhui   | 0.557 | 0.554 | 0.552 | 0.546 | 0.542 | 0.546 | 0.549 | 0.551 | 0.559 | 0.566 |
| Fujian  | 0.678 | 0.671 | 0.657 | 0.630 | 0.625 | 0.635 | 0.633 | 0.644 | 0.676 | 0.679 |
| Jiangxi | 0.588 | 0.563 | 0.545 | 0.545 | 0.547 | 0.557 | 0.564 | 0.578 | 0.592 | 0.607 |
| Shandong | 0.598 | 0.588 | 0.584 | 0.576 | 0.579 | 0.585 | 0.592 | 0.601 | 0.645 | 0.663 |
| Henan   | 0.591 | 0.577 | 0.555 | 0.524 | 0.500 | 0.488 | 0.483 | 0.485 | 0.507 | 0.510 |
| Hubei   | 0.468 | 0.472 | 0.480 | 0.492 | 0.499 | 0.507 | 0.512 | 0.515 | 0.550 | 0.560 |
| Hunan   | 0.556 | 0.555 | 0.555 | 0.545 | 0.534 | 0.527 | 0.524 | 0.528 | 0.560 | 0.570 |
| Guangdong | 0.997 | 0.985 | 0.995 | 0.995 | 0.969 | 0.974 | 0.964 | 0.939 | 0.997 | 0.996 |
| Guangxi | 0.567 | 0.555 | 0.541 | 0.515 | 0.486 | 0.457 | 0.440 | 0.441 | 0.463 | 0.471 |
| Hainan  | 0.563 | 0.565 | 0.570 | 0.561 | 0.559 | 0.571 | 0.550 | 0.533 | 0.533 | 0.523 |
| Chongqing | 0.495 | 0.486 | 0.495 | 0.507 | 0.520 | 0.540 | 0.556 | 0.576 | 0.635 | 0.652 |
| Sichuan | 0.493 | 0.492 | 0.492 | 0.479 | 0.486 | 0.496 | 0.508 | 0.521 | 0.548 | 0.555 |
| Guizhou | 0.336 | 0.341 | 0.356 | 0.356 | 0.355 | 0.357 | 0.362 | 0.360 | 0.366 | 0.362 |
| Yunnan  | 0.453 | 0.456 | 0.462 | 0.471 | 0.459 | 0.434 | 0.418 | 0.409 | 0.420 | 0.411 |
| Shanxi  | 0.504 | 0.492 | 0.483 | 0.483 | 0.478 | 0.476 | 0.481 | 0.486 | 0.506 | 0.515 |
| Gansu   | 0.416 | 0.421 | 0.424 | 0.419 | 0.415 | 0.413 | 0.413 | 0.417 | 0.418 | 0.416 |
| Qinghai | 0.300 | 0.302 | 0.307 | 0.316 | 0.314 | 0.318 | 0.309 | 0.301 | 0.293 | 0.286 |
| Ningxia | 0.305 | 0.293 | 0.291 | 0.288 | 0.276 | 0.275 | 0.270 | 0.273 | 0.274 | 0.268 |
| Xinjiang | 0.416 | 0.418 | 0.426 | 0.433 | 0.430 | 0.428 | 0.421 | 0.406 | 0.386 | 0.375 |

Table 2. Descriptive statistical analysis of total factor energy efficiency values

| Year | Min   | Max   | Avg. | S.D.  |
|------|-------|-------|------|-------|
| 2007 | 0.300 | 1.000 | 0.561 | 0.143 |
| 2008 | 0.290 | 0.990 | 0.553 | 0.143 |
| 2009 | 0.290 | 1.000 | 0.552 | 0.147 |
| 2010 | 0.290 | 1.000 | 0.549 | 0.151 |
| 2011 | 0.280 | 0.970 | 0.545 | 0.154 |
| 2012 | 0.280 | 0.970 | 0.547 | 0.159 |
| 2013 | 0.270 | 0.960 | 0.550 | 0.166 |
| 2016 | 0.270 | 0.950 | 0.555 | 0.172 |
| 2015 | 0.270 | 1.020 | 0.577 | 0.190 |
| 2016 | 0.270 | 1.030 | 0.583 | 0.197 |

As can be seen from the descriptive statistical results in table 2, nationwide, the average total factor energy efficiency shows an overall upward trend. The maximum value is relatively stable, but the minimum value shows a slight downward trend. At the same time, it can also be seen from the table that
its standard deviation value has significantly increased, indicating that there is a trend of widening differences in energy efficiency between regions in China and that regional development is unbalanced.

3.3. Spatial correlation analysis

3.3.1. Global spatial correlation analysis. According to the total factor energy efficiency of each province measured in the previous chapter, this paper calculated the Moran’s I of total factor energy efficiency of each province in China during the sample period. Given in table 3 in 2007-2016 China's provincial total factor of energy efficiency of Moran’s I, it can be seen that the Chinese provincial total factor of energy efficiency of Moran’s I is positive, and all significant at 1% level, suggesting that Chinese 30 provinces domain all the elements in the spatial distribution of the energy efficiency has a significant positive correlation, namely spatial dependence exists. In other words, the spatial distribution of China's total factor energy efficiency is not random, but a phenomenon of regional agglomeration.

| Year | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2016 | 2015 | 2016 |
|------|------|------|------|------|------|------|------|------|------|------|
| Moran’s I | 0.418 | 0.425 | 0.418 | 0.397 | 0.400 | 0.410 | 0.399 | 0.411 | 0.389 | 0.407 |
| Z     | 3.809 | 3.849 | 3.790 | 3.603 | 3.602 | 3.678 | 3.567 | 3.652 | 3.470 | 3.606 |
| P     | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |

3.3.2. Local spatial autocorrelation analysis. In order to facilitate observation and draw conclusions, this paper selected the Moran scatter plot in 2007 and 2016 to expand the description. It can be seen that most provinces are in the first (high-high) quadrant and the third (low-low) quadrant. It can be seen that the provinces in the first quadrant and the third quadrant together account for 80% of the total sample, which further confirms that there is a significant positive spatial autocorrelation of total factor energy efficiency in Chinese provinces. In the first quadrant, 9 provinces belong to the eastern region, accounting for up to 75%, which further confirms that the total factor energy efficiency in the eastern region is generally at a high level. In the third quadrant, there are 10 provinces in the central and western regions, accounting for 83.33%, indicating that most of the provinces in the western region are provinces with low total factor energy efficiency and are surrounded by other provinces with low total factor energy efficiency.

![Figure 1. 2007 and 2016 partial Moran scatter plot](image)

(Note: the number 1-30, on behalf of the Beijing, Tianjin, Hebei, Shanxi, Inner Mongolia, Liaoning, Jilin, Heilongjiang, Shanghai, Jiangsu, Zhejiang, Anhui, Fujian, Jiangxi, Shandong, Henan, Hubei, Hunan, Guangdong, Guangxi, Hainan, Chongqing, Sichuan, Guizhou, Yunnan, Shaanxi, Gansu, Qinghai, Ningxia and Xinjiang)
By comparing the 2007 and 2016 Moran scatter plot, the spatial dynamic transition process of total factor energy efficiency in different provinces in China can be further analyzed. Referring to the time-space transition measurement method proposed by Rey [13], the dynamic transition types of total factor energy efficiency in Chinese provinces are shown in the following three or four categories (as shown in table 4).

During the sample investigation, there were 24 provinces belonging to the fourth category of transition, accounting for 80% of the total. Eastern coastal provinces except Hainan province space transition phenomenon occurs, energy efficiency and total factor in the type of transition to a low by the high collection value to set the transfer of value area, visible, total factor of energy efficiency in China, there exist some obvious geographical distribution characteristics of "path dependence" has obvious concentration and high stability, can be concluded that in the future for a long while still in the eastern coastal areas will generally have higher total factor of energy efficiency, but with the change of other economic factors changes, the production activities and macro policy regulation, provincial total factor of energy efficiency of high value and low space distribution will be subject to change.

### Table 4. Space transition situation

| Transition type | Transition path | Representative province |
|-----------------|-----------------|------------------------|
| The transition of adjacent provinces in the correlation space | High - High→High - Low, Low - Low→Low - High, High - Low→High - High, Low - High→Low - Low | No |
| The whole transition of this region and its related space adjacent province domain | High - High→Low - Low, Low - Low→High - High | Jilin province |
| A provincial transition of the relative displacement caused by a horizontal change in the region | High - High→Low - High, Low - Low→High - Low, High - Low→Low - Low, Low - High→High - High | Guangxi province, Hainan province, Chongqing province, Liaoning province, Henan province |
| Provinces and their neighbors remain at the same level | | Other provinces |

### 4. Conclusions and Suggestions

#### 4.1. Conclusion

Based on the theoretical analysis framework of total factor energy efficiency, this paper studied the regional differences and influencing factors of total factor energy efficiency in China's provinces with the help of super efficiency SBM-DEA model, spatial correlation analysis and spatial panel econometric model, using panel data of 30 provinces from 2007 to 2016. The main conclusions are as follows:

1. Total factor energy efficiency of Chinese province based on super-efficiency SBM-DEA model. The effective provinces at the forefront of production are all in the eastern coastal areas, including Beijing, Shanghai and Guangdong province. Eastern total factor generally high energy efficiency as a whole is in the national leading level, followed by three provinces in northeast China, most of the provinces in central China's total factor of energy efficiency in the medium level, and the western region of Chongqing, Sichuan and Inner Mongolia, Fujian association of foreign languages and other three provinces total factor of energy efficiency into ten years are low, has been in a backward position of the country. The total factor energy efficiency of Chinese provinces generally shows a trend of gradual decrease from east to west. By analysis of the provincial total factor of energy efficiency in the area of
four major averages of regional total factor of energy efficiency, this paper found that the eastern region total factor of energy efficiency in the highest position, followed by the northeast region, middle region and west region difference is small, all elements of the lowest energy efficiency for the western region.

(2) Spatial correlation analysis of China's provincial total factor energy efficiency. With the help of the global Moran's I in spatial econometrics and the local Moran's I, this paper finds that the total factor energy efficiency of China's provinces calculated based on the super-efficiency SBM-DEA model has a significant positive correlation in spatial distribution and spatial dependence. The spatial distribution of China's total factor energy efficiency is not random, but a phenomenon of regional agglomeration. The local Moran scatter diagram of total factor energy efficiency in Chinese provinces shows that provinces in the first quadrant (high-high) and the third quadrant (low-low) together account for 80% of the total sample, which further confirms the significant positive spatial autocorrelation of total factor energy efficiency in Chinese provinces. In the first quadrant, 9 provinces belong to the eastern region, accounting for up to 75%, which further confirms that the total factor energy efficiency in the eastern region is generally at a high level. In the third quadrant, the provinces in the western region account for 83.33%, indicating that the provinces in the western region are mostly provinces with low total factor energy efficiency and surrounded by other provinces with low total factor energy efficiency. During the sample investigation in this paper, the provinces with spatial transition are Jilin, Guangxi, Hainan, Chongqing, Liaoning and Henan, which are mostly located in the central and western regions, and the transition types are mostly from high set value region to low set value region. However, there was no spatial transition in the 26 provinces, indicating that total factor energy efficiency had obvious "path dependence" characteristics in China's geographical distribution, with obvious agglomeration and high stability.

4.2. Suggestions

Based on the above empirical analysis results, this paper puts forward specific policy Suggestions as follows:

(1) Formulate different regional energy policies according to regional differences.

In this article, through statistical analysis and spatial analysis, found that total factor between different regions of China's energy efficiency has a larger difference, so in each region energy policy, can not ignore the existing regional differences, should be based on different regional present situation of the energy efficiency, formulate corresponding policies and measures, considering the actual development situation of different area, take the moderate policy, adjust measures to local conditions.

(2) Strengthen exchanges and mutual benefits between regions.

According to the empirical results of this paper, there is a significant spatial positive correlation between the total factor energy efficiency of Chinese provinces and cities, and there is a spatial spillover effect between the total factor energy efficiency of Chinese provinces and cities. Therefore, in the process of economic development in various regions, the government should issue relevant policies to strengthen the economic contact and interaction between regions, and promote the technology transfer and economic radiation between regions. While improving their own energy efficiency, each region actively USES the spatial spillover effect of energy efficiency to promote its own energy efficiency and at the same time promote the energy efficiency of surrounding provinces and cities, so as to achieve win-win cooperation among regions.

(3) Reduce government intervention in the economy and give full play to market forces.

The empirical results of this paper show that government intervention has a negative impact on the total factor energy efficiency of Chinese provinces, and excessive government intervention will affect the market's ability to automatically adjust resource allocation, which is not conducive to the improvement of energy efficiency. Therefore, the government should appropriately reduce its intervention in the market and, under reasonable supervision and guidance, believe in the self-regulating function of the market and the "invisible hand".
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