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Evaluation of the Implementation Effect of China's Industrial Sector Supply-Side Reform: From the Perspective of Energy and Environmental Efficiency

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Abstract: The analysis of the implementation effect of the supply-side reform (SSR) in the industrial sector of China's provinces and the reasons behind them are of great significance for China to formulate relevant policies in the future. However, this work has not yet been carried out. Industrial development performance is closely related to energy and environmental efficiency (EEE), and the effect of the SSR implementation is directly reflected in EEE. This study fills this gap by analyzing the EEE of 30 provinces in China from 2012 to 2017 using data envelopment analysis and Malmquist index methods. The results show that the positive effect of China's implementation of SSR has emerged. This positive effect is mainly reflected in the implementation of measures such as reducing overcapacity, which has promoted the technological innovation of enterprises. However, the low management level and resource-allocation efficiency hinder the further improvement of the implementation effect of the SSR, which should be paid special attention to in China's future supply-side reform. In addition, we believe that in the context of China's high-quality development and carbon neutrality goals, the SSR should be given more connotations, which are to increase the requirements for strengthening green and low-carbon development.

Keywords: China; supply-side reform; industry; DEA; energy and environmental efficiency

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1. Introduction

China is the largest developing country in the world. The country's economy has grown at an average rate of 9.28% over the past 40 years, far exceeding the world economy's 2.62% over the same period. Its gross domestic product (GDP) has grown from USD 364.4 billion in 1978 to USD 14.63 trillion in 2020 (2015 USD price), accounting for 17.88% of the global total [1]. Rapid economic growth is good, but high-quality economic development cannot be ignored. Obviously, China is not doing this well enough. Serious problems such as overcapacity, backward production capacity, inefficient allocation of production factors, high pollutants (sulfides, nitrogen oxides, dust, etc.), and carbon dioxide emissions have appeared in some industries. As can be seen from Figure 1, China's current $PM_{2.5}$ and CO_2 emission intensity are more than two times higher than those of the United States and the European Union. In recent years, China has begun to pay attention to the prominent problems exposed on the supply side of the economic and social system and has implemented a series of reform measures such as accelerating the exit of excess and outdated production capacity, reducing pollutant and CO_2 emissions, and improving the efficiency of resource allocation. These measures are intended to improve the quality and efficiency of the supply system and are known as supply-side reforms (SSR).

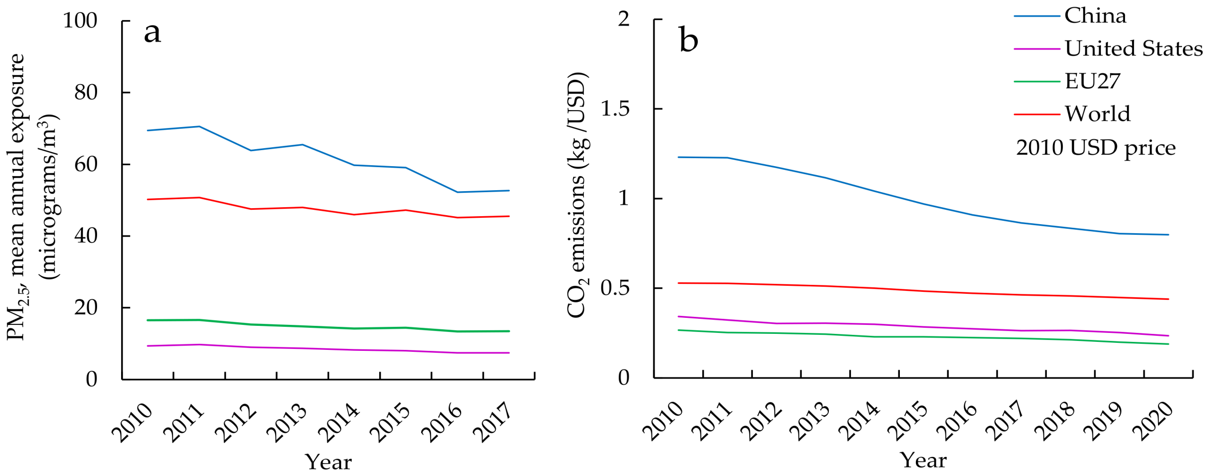

Figure 1. $PM_{2.5}$ (**a**) and CO_2 (**b**) emission levels in the world and major countries [2,3].

The strategic deployment was formally proposed by China in 2015. So far, China's SSR has made great progress, especially in the industrial sector. The industrial sector was an important object to implement the SSR. China completed the 13th Five-Year Plan to reduce production capacity two years ahead of schedule, with a total of 810 million tons of outdated coal production capacity withdrawn, and more than 20 million kilowatts of outdated coal-fired power units eliminated and shut down [4]. In addition, China withdrew 170 million tons of steel production capacity during the 13th Five-Year Plan period [5]. This shows that the SSR of China's industrial sector has made overall positive progress. However, it is widely known that China has more than 30 provinces with different industrial structures and economic development levels, and the focus of the SSR is also different. So, this leads to a series of questions worth thinking about; that is, does the effect of SSR implementation vary by province? What is the reason for the difference? In 2017 and 2020, China proposed the goals of achieving high-quality development and carbon neutrality, respectively. The SSR is one of the key tasks to promote high-quality development and carbon neutrality [6]. China needs the answers to the above questions as references for formulating and implementing relevant policies to promote high-quality development and carbon neutrality. This study will try to answer those questions.

The rest of this study will be arranged as follows: Section 2 summarizes the innovations of this study through a literature review; Section 3 introduces the research framework, research methods, and data; Section 4 analyzes the results and carries out relevant discussions, and Section 5 summarizes some conclusions and puts forward some policy suggestions based on the research results.

2. Literature Review

Industrial development performance is closely related to energy and environmental efficiency (EEE), and the implementation effect of the SSR is directly reflected in EEE. There are two widely used methods for evaluating efficiency: the stochastic frontier approach (SFA) and the data envelopment analysis (DEA) model. The SFA is commonly used in a single-output scenario [7,8]. The DEA method is used to evaluate the relative efficiency of a group of homogeneous decision-making units (DMUs), especially for multiple-input and multiple-output scenarios [9,10]. The early forms of the DEA methods are mainly the CCR model based on the assumption of constant returns to scale [11] and the BCC model based on the assumption of variable returns to scale [12]. However, the CCR and BCC models are input- and output-oriented radial efficiency evaluation methods, respectively, which ignore the input and output slacks, making the efficiency evaluation less accurate [7]. Later, a non-radial DEA model with input and output slacks, slacks-based measure DEA (SBM-DEA), was proposed [13]. In addition, the results of the SBM-DEA model have multiple effective DMUs with an efficiency value equal to 1, which makes it difficult to further rank the effective DMUs. To solve this problem, a super-efficient SBM (S-SBM) model is proposed, the main idea of which is to allow the efficiency value of the DMUs to be greater than 1 [14]. Based on the panel data of 30 provinces and cities in China from 2009 to 2017, Song et al. [15] used the S-SBM model to measure the energy and power efficiency, showing that the SSR has effectively promoted the improvement of China's overall efficiency, but there are differences between regions. Among them, the reform effect of the northeast and central regions is slightly lower than that of the coastal and western regions. This is one of the few studies currently evaluating the effect of China's SSR implementation and it only focuses on the power sector. From the perspective of research methods, (1) the S-SBM model can be used to evaluate the relative efficiency of provincial industry at a certain time [16], but development is a dynamic process involving technological advances and changes in efficiency; and (2) the S-SBM model does not take into account the undesirable output very well [17]. Therefore, it is difficult to comprehensively analyze the implementation effect of the SSR only with the S-SBM model. Boulter [18] analyzes the relevant statistical data on the profitability of China's steel sector, bankrupt enterprises, etc., and believes that the SSR policy is an important component of China's economic policy agenda. Its implementation has achieved great success in reducing excess and outdated production capacity and in increasing profits in the industrial sector.

In addition, other aspects of SSR have also received attention and in-depth research in the academic community. Xi et al. [19] built a structural model with four sectors to simulate the Chinese economy, showing that the de-capacity policy is at the cost of GDP losses, but some production-capacity reductions in both high-energy-consuming and fossil-energy sectors can be achieved with smaller cost to achieve the same policy goals. He and Lin [20] used the principal-component analysis method to calculate the operating index of China's energy industry and used the index to examine the cyclical fluctuation trend. They pointed out that while continuing to advance the green-energy strategy, advancing SSR policy to eliminate excess capacity in the energy industry is a key solution to reversing the supply-demand imbalance and falling prices. Based on the analysis of the impact of China's macro policies on capital-market efficiency from 2008 to 2016, Jiang et al. [21] found that the adjustment of fiscal and monetary policies has great potential because input factors are obviously interchangeable in the SSR. Hu et al. [22] used the Q-methodology to assess the attitudes and needs of different types of farmers towards management incentives during the agricultural SSR. Zhou et al. [23] built a two-stage optimization model to optimize the liner transportation network of the China Ocean Shipping Company under the background of the SSR. Some of these studies only take the SSR as the research background, some optimize some strategies of the SSR, some discuss the perceptions and reactions of the stakeholders to the SSR, and some only mention the SSR during the discussion. All in all, the focus of these studies is not on the implementation effects of the SSR.

By reviewing the existing research, it can be found that (1) there are few studies evaluating the implementation effect of the SSR, especially regarding the industrial sector, and (2) only using the S-SBM model to analyze the efficiency and then evaluate the implementation effect of the SSR cannot analyze the efficiency changes on the time scale of each decision-making unit (DMU), nor can it take into account undesirable outputs well, which may make the research results deviate from the actual situation.

This study analyzes the EEE and dynamic change of total factor productivity (TFPC) of the industrial sector by using S-SBM considering the undesirable output (S-SBM-U) model and DEA-Malmquist index methods and evaluates the implementation effect of the SSR of China's provincial industrial sector. The S-SBM-U model is an improved S-SBM model developed by Huang et al. [17] that considers undesirable outputs. The DEA-Malmquist index method can be used to analyze the TFPC, which includes a change in production technology (TC) and a change in technical efficiency (TEC) [24], and has been widely used [25,26].

The contributions are as follows: (1) from the perspective of the EEE, analyzing the implementation effect of China's provincial industrial sector SSR can enrich the research content of China's SSR-related research fields; and (2) the application of the DEA-Malmquist index method and the S-SBM-U model, supports the evaluation of the implementation effect of China's provincial industrial sector SSR with a more scientific theoretical method system.

3. Methods and Data

3.1. Research Framework

The research ideas and framework are described here. First, the panel data of inputs in the provincial industrial sector (capital stock, employees, and energy consumption) and outputs (industrial added value, industrial SO_2 emissions, and industrial CO_2 emissions) are adopted to evaluate the EEE and its rankings from 2012–2017 through the S-SBM-U model. It should be noted here that industrial production will emit a variety of pollutants and wastes, including SO_2, nitrogen oxides and other waste gases, PM_{10} and $PM_{2.5}$ and other particles, wastewater and waste residue, etc. However, to avoid too many DMUs being evaluated as DEA-effective, the total number of input and output indicators should not be more than 20% of the total number of DMUs [7]. Therefore, this study only selected SO_2 emissions as one of the two undesired outputs. Second, we adopt the DEA-Malmquist index method to analyze the TFPC, TC, and TEC of each DMU. Finally, based on the above results, the key points of promoting the SSR of the industrial sector in each province are discussed. The research framework of this study is shown in Figure 2.

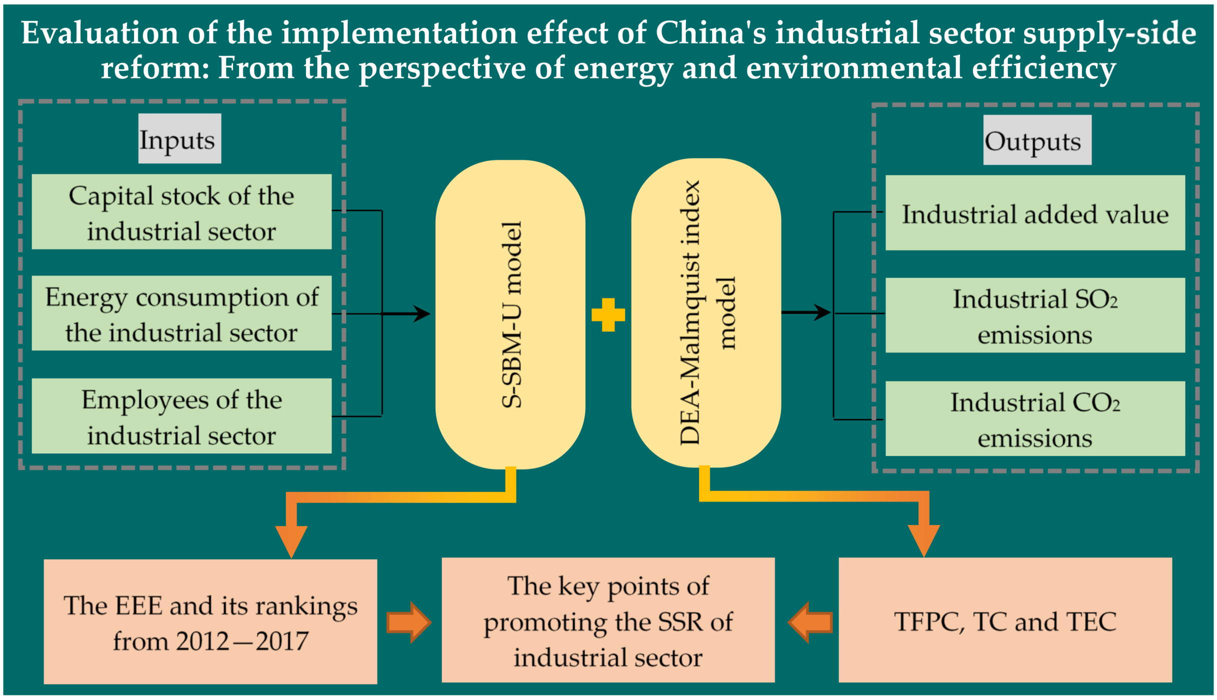

Figure 2. The research framework.

3.2. S-SBM-U Model

The S-SBM-U model is an improved S-SBM model developed by Huang et al. [17] and it has been widely used [17,27]. We assume that there are n-many DMUs, and each DMU has the same kind of input, desirable output, and undesirable output. m, q_1, and q_2 are the numbers of inputs, desirable outputs, and undesirable outputs, respectively. X, Y, and B are defined as the matrices of inputs, desirable outputs, and undesirable outputs of all DMUs, respectively, where $X = (x_1, \cdots, x_n) \in R^{m \times n}$, $Y = (y_1, \cdots, y_n) \in R^{q_1 \times n}$, and $B = (b_1, \cdots, b_n) \in R^{q_2 \times n}$.

The S-SBM-U model is shown in Equation (1), from the studies of Huang et al. [17] and Yu et al. [27]:

$$\rho=\min\frac{1+\frac{1}{m}\sum_{i=1}^{m}\frac{s_i^-}{x_{ik}}}{1-\frac{1}{q_1+q_2}\left(\sum_{r=1}^{q_1}\frac{s_r^+}{y_{rk}}+\sum_{t=1}^{q_2}\frac{s_t^{b-}}{b_{tk}}\right)}$$
$$s.t.\begin{cases}\sum_{j=1,j\neq k}^{n}x_j\lambda_j-s^-\leq x_k\\ \sum_{j=1,j\neq k}^{n}y_j\lambda_j+s^+\geq y_k\\ \sum_{j=1,j\neq k}^{n}b_j\lambda_j-s^{b-}\leq b_k\\ 1-\frac{1}{q_1+q_2}\left(\sum_{r=1}^{q_1}\frac{s_r^+}{y_{rk}}+\sum_{t=1}^{q_2}\frac{s_t^{b-}}{b_{tk}}\right)>0\\ \lambda,s^-,s^+,s^{b-}\geq 0\\ i=1,2,\cdots,m;r=1,2,\cdots,q_1;t=1,2,\cdots,q_2;j=1,2,\cdots,n(j\neq k)\end{cases} \quad (1)$$

where ρ represents the value of EEE; k is the number of the evaluated DMU; x, y, and b are the indicators of input, desirable output, and undesirable output, respectively; s_i^-, s_r^+, and s_t^{b-} stand for the slacks of input, desirable output, and undesirable output, respectively; s^-, s^+, and s^{b-} are the slack matrices of input, desirable output, and undesirable output; and λ is the weight vector.

3.3. DEA-Malmquist Index Model

The DEA-Malmquist index model is shown in Equation (2):

$$M_0(x_t,y_t,x_{t+1},y_{t+1})=\sqrt{\frac{D_0^t(x_{t+1},y_{t+1})}{D_0^t(x_t,y_t)}\cdot\frac{D_0^{t+1}(x_{t+1},y_{t+1})}{D_0^{t+1}(x_t,y_t)}}=TC\cdot TEC \quad (2)$$

where $M_0(x_t,y_t,x_{t+1},y_{t+1})$ is the Malmquist index, which represents the TFPC from time t to t + 1; x_t, x_{t+1} are the inputs of time t and t + 1, respectively, and y_t, y_{t+1} are the outputs of time t and t + 1, respectively; $D_0^t(x_t,y_t), D_0^t(x_{t+1},y_{t+1})$ denote the distance function at time t and t + 1, respectively, with the technical frontier of time t as the reference; and $D_0^{t+1}(x_t,y_t), D_0^{t+1}(x_{t+1},y_{t+1})$ denote the distance function at time t and t + 1, respectively, with the technical frontier of time t + 1 as the reference.

3.4. Data

This study only evaluates the industrial sector EEE of 30 provinces in China, excluding Tibet, Hong Kong, Macau, and Taiwan, from 2012 to 2017. Referring to the input and output indicators used in existing studies [28–31], three indicators including the capital stock of the industrial sector, the number of employees, and energy consumption were selected as inputs; industrial added value was selected as a desirable output, and; SO_2 emissions and CO_2 emissions were designated as undesirable outputs. The specific data sources and processing of each indicator are as follows:

(1) The capital stock: there are no official data on the capital stock of the industrial sector, so they would be obtained through calculating based on the method of equal-capital-output ratio [32], as shown in Equation (3):

$$K_{i,t}=Y_{i,t}\cdot K_{i,t}^N/Y_{i,t}^N \quad (3)$$

where $Y_{i,t}$ is the industrial added value (it has been converted into constant 2012 prices) of i province at time t; $K_{i,t}^N$ is the total social capital stock of i province at time t; and $Y_{i,t}^N$ is the gross regional production (in constant 2012 prices) of i province at time t. The total social capital stock in various provinces is calculated by the perpetual-inventory method, as shown in Equation (4):

$$K_{i,t}^{N} = (1-\delta)\cdot K_{i,t-1}^{N} + I_{i,t}^{N} \quad (4)$$

where δ denotes depreciation rate, 9.6% [33] and $I_{i,t}^{N}$ is the gross fixed capital formation (in constant 2012 prices) of i province at time t. the initial total social capital stock is calculated based on the method proposed by Young [34], dividing the gross fixed capital formation in 2012 by 10%. The data needed in the calculation of the capital stock of the industrial sector include the gross fixed capital formation, price index for investment in fixed assets, producer price index for industrial product, gross regional production, and industrial added value. These data are from the Provincial Statistical Yearbooks of 2013–2021 [35] and China Statistical Yearbooks of 2013–2021 [36]. It should be noted here that the data on the gross fixed capital formation of each province in China was not released after 2018, but the gross regional production and industrial added value were revised later. Therefore, we revised the data on the gross fixed capital formation based on the changes in gross regional production published around 2018, so as for it to be more reasonably applied to this study.

(2) The number of employees: its data comes from the Provincial Statistical Yearbooks of 2013–2018 [37].

(3) Energy consumption: according to the conversion coefficient from physical units to coal equivalent [38], the physical quality of different types of energy consumption in various provincial industrial sectors from 2012 to 2015 could be converted into the quantity with the coal equivalent as the unit [39]. The energy consumption data in a coal equivalent unit from 2016–2017 are directly obtained from Shan et al. [40].

(4) Industrial added value: the data are obtained from the Provincial Statistical Yearbooks of 2020–2021 [41].

(5) CO_2 emissions: its data comes from existing studies by Shan, et al. [39] and Shan, et al. [40].

(6) SO_2 emissions: the SO_2 emissions data comes from the Provincial Statistical Yearbooks from 2013 to 2018 [37]. What should be explained is that there are no official data on SO_2 emissions from the industrial sector of Hebei, Hainan, and Qinghai from 2016 to 2017. The difference between the total SO_2 emissions in 2016 and 2017 and the average SO_2 emissions of other sectors for 2014 and 2015 are regarded as the SO_2 emissions from the industrial sector in 2016 and 2017.

The statistical description of input and output data is shown in Figure 3, including maximum, minimum, mean, and standard deviation. The annual change rates of average industrial added value, energy consumption, and CO_2 and SO_2 emissions from 2012 to 2015 were 7.53%, 3.06%, 0.28%, and −6.64%, respectively. This shows that China's industrial sector is gradually upgrading, and economic development is weakly decoupled from energy consumption and CO_2 emission, and deeply decoupled from SO_2 emission. Focusing on the situation in 2016–2017, the growth rates of industrial added value and energy consumption have both slowed down, but the growth rate of energy consumption has declined more, and they have slowed down to 3.35% and 0.22%, respectively. The decrease rate of SO_2 increased to 38.52% annually. In addition, during the period of the SSR, the number of employees has declined. This shows that SSR has brought pain to the development of the industrial economy, but it has indeed promoted high-quality development, which is the result of the exit of excess capacity, the optimal allocation of resources, technological innovation, and the rapid development of high value-added industries.

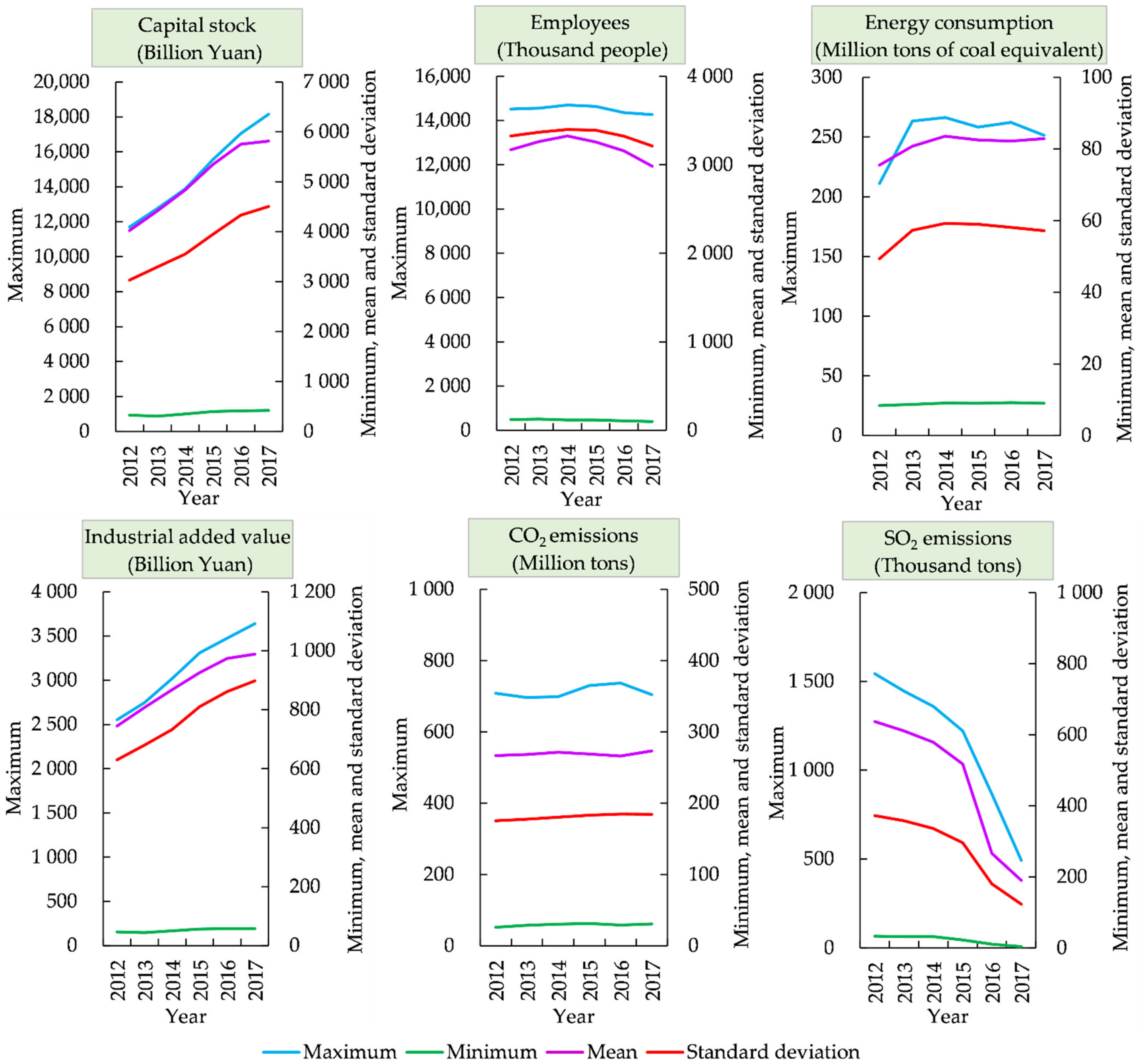

Figure 3. Statistical description of input and output data.

4. Results and Discussion

4.1. The EEE of the Industrial Sector in Various Provinces

The EEE values of the industrial sector in various provinces from 2012 to 2017 are shown in Table 1. Regardless of the period of the SSR, the EEE values of Beijing, Shaanxi, Hainan, and Shanghai are always greater than 1. The four provinces can be divided into three categories. One is that Beijing and Shanghai are the two most developed provinces and cities in China, and their industrial sectors have industrial systems with high value-added, low energy consumption, and low CO_2 and pollutant emissions. The second is Shaanxi, which is a province with developed heavy industries such as coal mining and thermal power production. Due to the late construction time and advanced technology and management, the resource allocation is relatively optimized. The third is Hainan, which has the advantage of being a latecomer in industrial development and has introduced advanced management systems and experience at home and abroad. EEE is equal to the product of pure technical efficiency (PTE) and scale efficiency (SE) (see Figure 4). The management levels of the four provinces are very good and the PTE is greater than 1. However, for SE, except Beijing, other provinces are below 1, especially Hainan. Obviously, the focus of their future SSR is to improve SE by optimizing the industrial scale.

Table 1. The energy and environmental efficiency (EEE) of the industrial sector in various provinces from 2012 to 2017.

Provinces (DMUs)	2012	2013	2014	2015	2016	2017
Beijing	1.09	1.14	1.17	1.21	1.28	1.22
Tianjin	0.43	0.41	0.39	0.39	0.37	0.39
Hebei	0.38	0.38	0.36	0.37	0.36	0.32
Shanxi	0.42	0.43	0.40	0.35	0.33	0.33
Inner Mongolia	0.34	0.37	0.35	0.38	0.37	0.50
Liaoning	0.35	0.34	0.32	0.34	0.35	0.35
Jilin	0.28	0.29	0.29	0.28	0.27	0.27
Heilongjiang	0.71	0.75	0.58	0.46	0.38	0.36
Shanghai	1.06	1.05	1.05	1.04	1.04	1.03
Jiangsu	0.62	0.52	0.49	0.49	0.47	0.45
Zhejiang	0.69	0.61	0.58	0.57	0.54	0.49
Anhui	0.52	0.48	0.45	0.43	0.41	0.39
Fujian	0.62	0.56	0.52	0.50	0.48	0.44
Jiangxi	0.62	0.51	0.48	0.46	0.43	0.38
Shandong	0.44	0.41	0.39	0.39	0.37	0.35
Henan	0.50	0.45	0.39	0.38	0.36	0.34
Hubei	0.66	0.58	0.50	0.57	0.55	0.49
Hunan	0.58	0.54	0.53	0.57	0.47	0.41
Guangdong	1.01	0.72	0.67	0.70	0.61	0.54
Guangxi	0.36	0.33	0.32	0.32	0.30	0.28
Hainan	1.03	0.54	1.02	1.03	1.02	1.03
Chongqing	0.50	0.52	0.48	0.47	0.45	0.42
Sichuan	0.48	0.48	0.46	0.46	0.44	0.41
Guizhou	0.37	0.41	0.39	0.43	0.40	0.40
Yunnan	0.53	0.59	0.68	1.00	1.01	0.59
Shaanxi	1.06	1.07	1.05	1.05	1.04	1.03
Gansu	0.54	1.00	0.50	0.48	0.49	0.37
Qinghai	0.27	0.28	0.26	0.27	0.28	0.26
Ningxia	0.33	0.34	0.32	0.32	0.32	0.31
Xinjiang	1.03	1.00	1.02	1.01	0.60	0.59

Focusing on inefficient DMUs, it is found that even after two years of the SSR, the EEE of economically developed provinces, such as Guangdong, Zhejiang, Jiangsu, Fujian, and Tianjin (the top five provinces in terms of per capita GDP, except for Beijing and Shanghai), is generally lower than 1. The average values of 2016 and 2017 are 0.57, 0.52, 0.46, 0.46, and 0.38, respectively. From the perspective of PTE and SE, the low EEE of Guangdong, Zhejiang, and Jiangsu in these provinces is mainly caused by low SE. The low SE is mainly due to the development of their labor-intensive processing industries (see Figure 4). This industrial structure cannot be changed through the SSR in the short term, but it should also be focused on in future SSR. In contrast, Tianjin's low EEE is mainly caused by low PTE, which indicates that in the future SSR, attention should be paid to improving the management level reforming the management system, and unleashing the vitality of the industrial sector to maximize the output of input factors.

For provinces with relatively backward economic development (such as Inner Mongolia, Sichuan, Shanxi), their DEA is inefficient. From the perspective of PTE and SE (see Figure 4), the main reason for the inefficiency of DEA is the low PTE. Most of these provinces have many traditional large-scale industrial enterprises with relatively backward management systems. Improving PTE through the management system reform should be an important aspect of the SSR in the future.

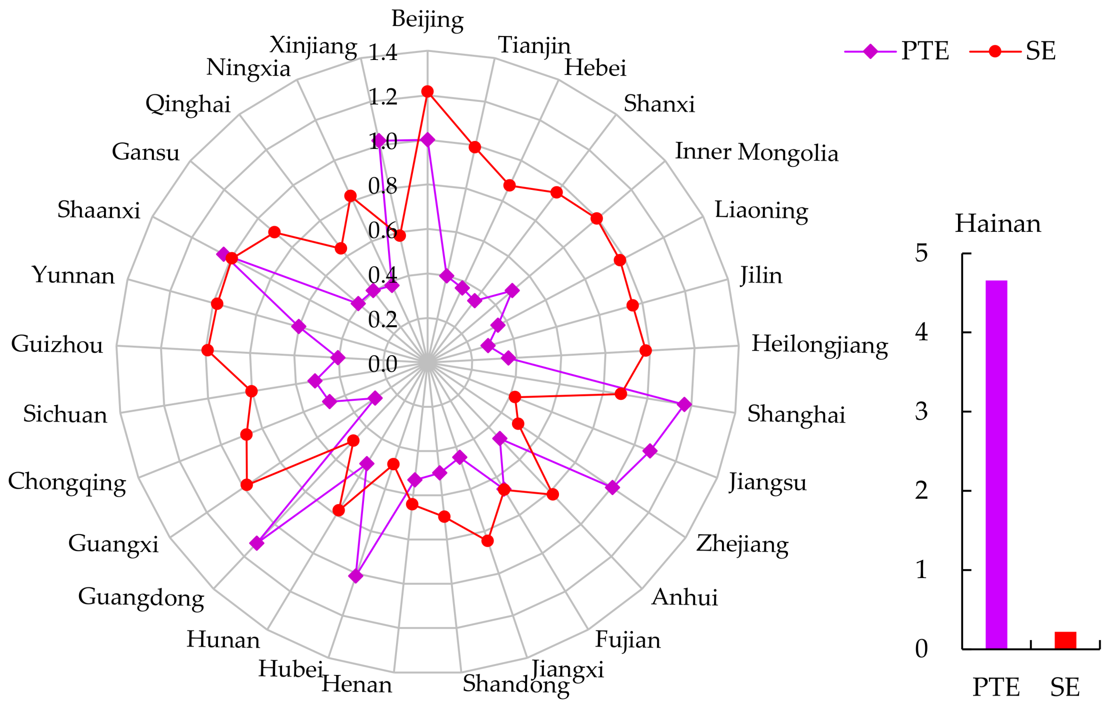

Figure 4. The pure technical efficiency (PTE) and scale efficiency (SE) of the industrial sector in various provinces in 2017. The PTE of Hainan Province is too large to display in the figure on the left, which would affect the display effect of the data of other provinces. Therefore, it is independently displayed in the bar chart on the right.

In addition, for inefficient DMUs, we find that the EEE of most provinces and cities show downward trends, even under the SSR. For example, the EEE of Hebei from 2016 to 2017 was 0.36 and 0.30, respectively. This shows that the progress of the SSR in Beijing, Shanghai, Shaanxi, and Hainan Tianjin is generally better than that in other provinces and cities. Of course, this does not mean that other provinces and cities have made poor progress in the SSR. For example, the iron and steel production capacity in Hebei dropped by 82.12 million tons. All these are great achievements in the SSR.

4.2. The EEE Rankings of the Industrial Sector in Various Provinces

The EEE evaluated by the S-SBM-U model is relative efficiency. It cannot be used to compare industrial development levels of the same province in different years, but it can compare different provinces. The changing trend of the rankings of the efficiency values in the industrial sector in various provinces is shown in Figure 5. The EEE rankings of the industrial sector in some provinces are relatively stable, even during the period during which the SSR policy was promoted. These provinces can be divided into two types. One type includes Beijing, Shanghai, Zhejiang, and Shaanxi, whose industrial economic development is at a high level and which demonstrates positive progress in the SSR. During the SSR, Beijing gradually closed all of its coal-fired power plants. Therefore, its EEE value is always ranked first. The other type includes provinces with low industrial-development levels and relatively small progress in the SSR, such as Jilin, Ningxia, and Qinghai. Of course, this does not refer to the total amount but compared to other provinces.

In addition, the implementation of the SSR has promoted improvements in the rankings of some provinces, including Tianjin, Inner Mongolia, Liaoning, Hainan, Chongqing, Sichuan, and Guizhou. This shows that the industrial development progress of the provinces assisted by the SSR is higher than the national average. In contrast, some provinces, such as Heilongjiang, Jiangxi, Shandong, and Hunan, have insufficient potential or small progress in the SSR, which leads to the decline of their EEE rankings for the period of the SSR.

Region	Provinces	2012	2013	2014	2015	2016	2017
North China	Beijing	1	1	1	1	1	1
	Tianjin	21	21	21	21	20	17
	Shanxi	22	20	19	25	26	25
	Hebei	23	24	24	24	23	26
	Inner Mongolia	27	25	25	22	21	8
Northeast China	Heilongjiang	7	6	8	17	19	21
	Liaoning	26	27	28	26	25	22
	Jilin	29	29	29	29	30	29
East China	Shanghai	3	3	3	3	3	4
	Zhejiang	8	8	9	9	9	9
	Jiangsu	10	15	14	12	13	11
	Jiangxi	11	16	16	15	16	19
	Fujian	12	11	11	11	11	12
	Anhui	16	18	18	19	17	18
	Shandong	20	22	23	20	22	23
Central China	Hubei	9	10	13	8	8	10
	Hunan	13	12	10	10	12	14
	Henan	18	19	22	23	24	24
South China	Hainan	4	13	5	4	4	3
	Guangdong	6	7	7	7	6	7
	Guangxi	25	28	27	28	28	28
Southwest China	Yunnan	15	9	6	6	5	6
	Chongqing	17	14	15	14	14	13
	Sichuan	19	17	17	16	15	15
	Guizhou	24	23	20	18	18	16
Northwest China	Shaanxi	2	2	2	2	2	2
	Xinjiang	5	4	4	5	7	5
	Gansu	14	5	12	13	10	20
	Ningxia	28	26	26	27	27	27
	Qinghai	30	30	30	30	29	30

Figure 5. The EEE rankings of the industrial sector in various provinces from 2012–2017.

An analysis of the EEE rankings of seven regions in China, covering different provinces, found that almost all the provinces in Southwest China continued to improve their rankings in the period of the SSR. Southwest China, especially the urban agglomeration construction centered on Chengdu and Chongqing, became part of a national strategy in 2016. It is positioned as an important modern industrial base in China, attaches importance to the development of high-tech industries, and strengthens the SSR as one of its early goals.

4.3. The TFPC of the Industrial Sector in Various Provinces

The TFPC (Malmquist index), TEC, and TC of the industrial sector in each province from 2012 to 2017 are shown in Figures 6–8, respectively. To make it easier to compare the impact of the SSR on EEE, the figure shows the mean value of the Malmquist index before and after the SSR. The Malmquist index in all provinces has been basically greater than 1 since 2012, indicating that the industrial sector in all provinces has been optimizing and upgrading, which can also be confirmed by the data of industrial added value, energy consumption, and CO_2 and SO_2 emissions shown in Figure 3. Then we look at the contribution of TEC and TC to TFPC. The TC of all provinces is greater than 1; only some provinces have TEC greater than 1 in some time periods, indicating that the total factor productivity improvement in all provinces is mainly due to the progress of production technology. Specifically, the main reason why the TEC of most provinces in China is lower than 1 is that under the background of economic transformation to high-quality development, various industries have problems such as overcapacity and backwardness, and declining operations and profitability. This also indicates that their industrial structure, organizational management level, and other aspects are still at a low level, and there is still room for improvement. TC is greater than 1 in all provinces and time periods, which shows that China's industrial sector has always attached great importance to technological innovation. Innovation is regarded by China as the primary driving force for development.

Comparing the TFPC, TEC, and TC before and after 2015, the TC value of most provinces increased because of the SSR, while the TEC value of most provinces decreased after the implementation of the SSR policy. For the first phenomenon, we believe that the SSR in these provinces has achieved positive results in the withdrawal of backward industries and the introduction of advanced technologies. For the second phenomenon, we believe that these provinces have not fully recovered from the pain caused by SSR, and their ability to reform management systems and optimize resource allocation has not recovered to the level before the SSR. It is expected that the Malmquist index of provinces should be larger during the SSR, but we find that this is not the case, and the Malmquist index of some provinces decreases instead. Specifically, the indices of Beijing, Inner Mongolia, Hainan, and Shaanxi increased significantly during the SSR, indicating that their SSR achieved great results. As we mentioned in Section 4.1, their industrial system underwent a high level of upgrading and optimization during the SSR. This also echoes the results obtained in Section 4.2 that the SSR have helped them expand their developmental advantages. In addition, the Malmquist index of Tianjin, Shanxi, Liaoning, Jilin, Heilongjiang, Shanghai, Jiangsu, Anhui, Fujian, Jiangxi, Shandong, Henan, Hubei, Guangxi, Chongqing, Yunnan, Gansu, Qinghai, Ningxia, and Xinjiang also improved after the SSR. The Malmquist index increased from 1.02 in 2012–2015 to 1.07 in 2015–2017, an increase of 4.43%. Their industrial sectors achieved more effective development during the SSR period. The reason is mainly that (1) both technological progress and technological efficiency are promoted, for example, in Tianjin, Shanxi, Inner Mongolia, Liaoning, Heilongjiang, Jiangsu, Anhui, Fujian, and Henan. Their SSR has achieved positive results in management-system reform, optimization of resource allocation, etc., and continues to vigorously introduce new technologies to promote industrial upgrading. (2) The pulling effect of technological progress completely offset the decline of technological efficiency contribution in Beijing, Jilin, Shanghai, Jiangxi, Shandong, Hubei, Guangxi, Hainan, Chongqing, Yunnan, Shaanxi, Gansu, Qinghai, Ningxia, and Xinjiang. The positive effects of their SSR in management system reform and resource allocation have yet to appear. In other provinces, the Malmquist index fell during the SSR period, from 1.04 in 2012–2015 to 1.02 in 2015–2017, a decrease of 2%. There are two different reasons behind this. (1) Both technological progress and technological efficiency have negative effects, such as in Guangdong. Its SSR has not achieved positive results in terms of management-system reform and resource allocation, and its willingness to introduce new technologies has not returned to the level before the reform. (2) The increase in the contribution of technological progress is weaker than the decrease in the contribution of technical efficiency in Hebei, Zhejiang, Hunan, Sichuan, and Guizhou. The positive effects of their SSRs in optimizing the industrial structure and resource allocation have yet to emerge.

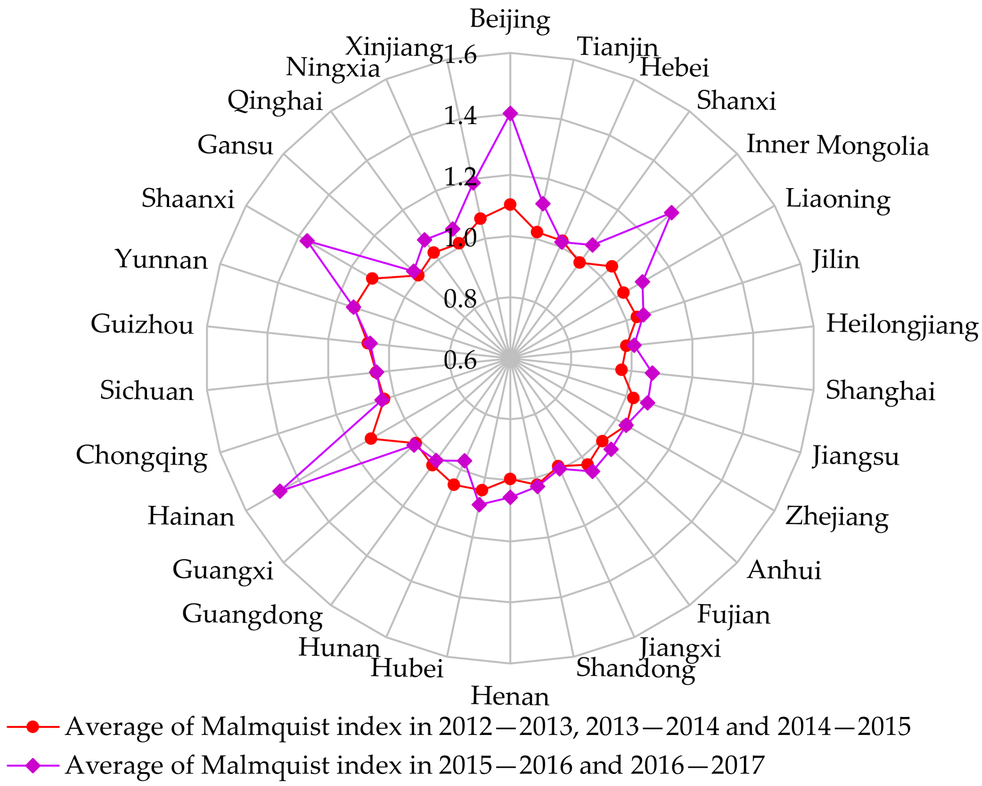

Figure 6. The Malmquist index of the industrial sector in various provinces from 2012–2017.

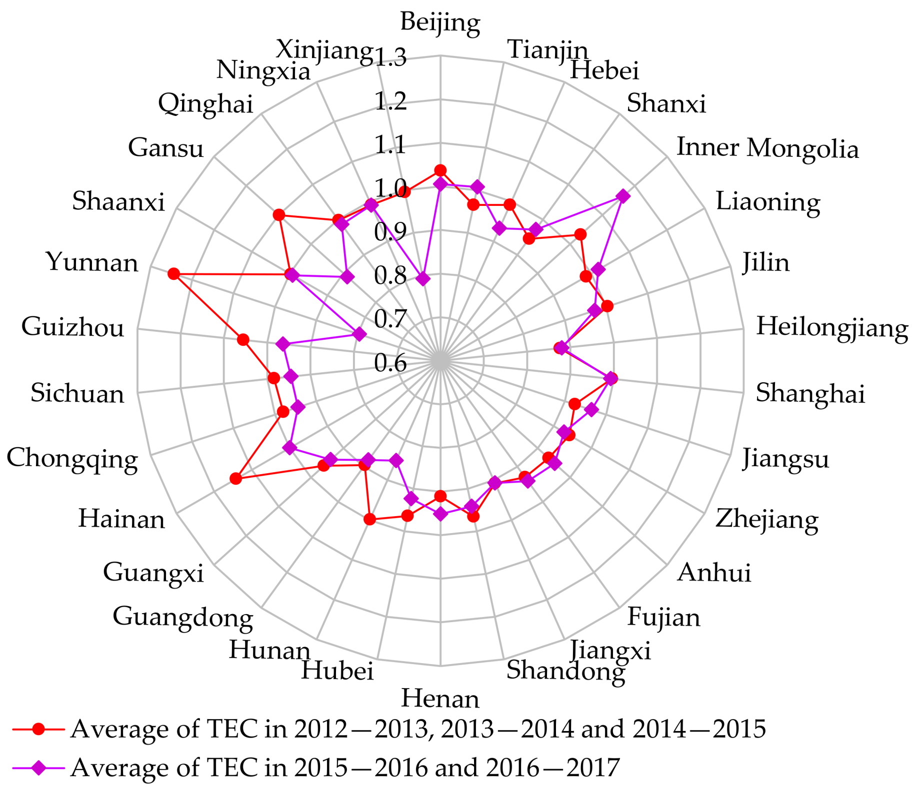

Figure 7. The change in technical efficiency (TEC) of the industrial sector in various provinces from 2012–2017.

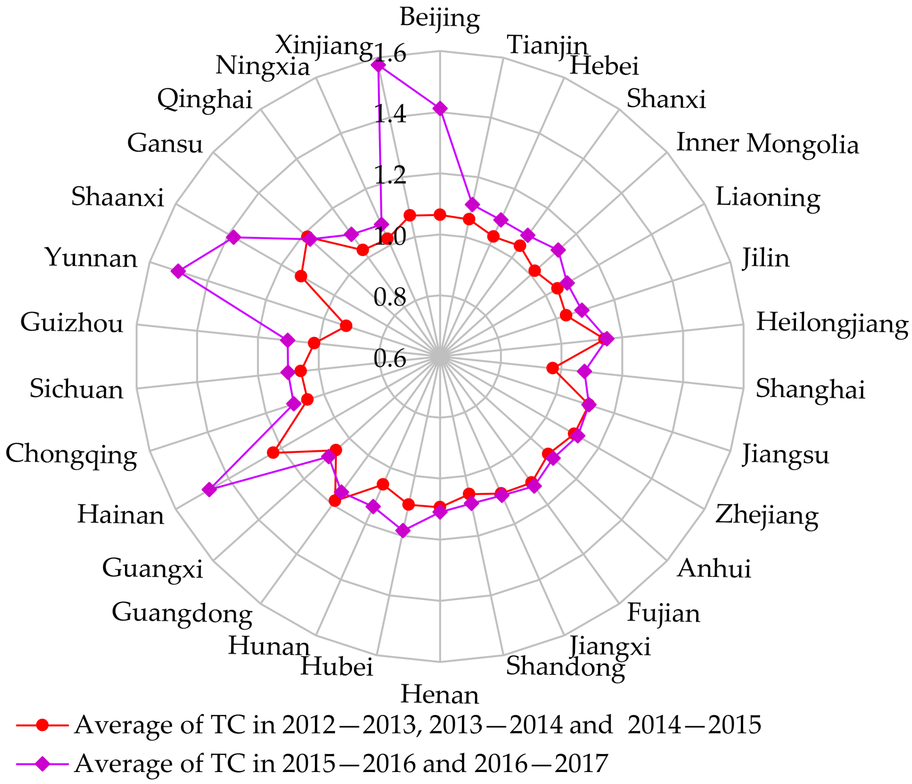

Figure 8. The change in production technology (TC) of the industrial sector in various provinces from 2012–2017.

4.4. Discussion

The SSR policy is not independent; it is complementary to other policies in China. In 2017, China put forward the goal of high-quality development. High-quality development emphasizes an innovative, high-efficiency, green and low-carbon approach to promote stable and sustainable economic growth and meet the growing needs of the people for a better life. The SSR is to improve the market vitality, innovation environment, production efficiency, supply efficiency, and supply quality of the supply side by implementing the policy of "three eliminations, one reduction and one supplement", especially the overcapacity policy. There is no doubt that the SSR is not only the main line of high-quality development but also the focus of high-quality development [42]. Of course, high-quality development also puts forward higher requirements for SSR, especially in terms of green and low-carbon supply, which requires companies to use lower-carbon, low-pollutant energy, and raw materials. In addition, China announced in September 2020 its goal of achieving carbon peaking by 2030 and carbon neutrality by 2060. The SSR policy will effectively improve energy efficiency, slow down the growth of carbon emissions and even reduce carbon emissions, and promote the realization of the goals of carbon peaking and carbon neutrality. However, it is clear that the current SSR policy and its intensity are far from meeting the requirements for achieving carbon neutrality. China needs to further accelerate the withdrawal of outdated production capacity, especially to reshape the whole social system in terms of energy supply, energy consumption, raw material supply, raw material utilization equipment, facilities, and management measures.

Through systematic research, this paper confirms that China's SSR has caused the industrial sector to experience pain, but there is no doubt that the SSR has a positive effect on the development of China's industrial sector, and this positive effect has begun to appear in some provinces. Our findings are consistent with the statement published by the Chinese government [43,44]. It is believed that with the further deepening of the SSR, the development level of the industrial sector will be further improved. In addition, both high-quality development and carbon neutrality goals emphasize green and low-carbon development, which is more conducive to improving the efficiency of provinces with developed heavy industries (such as cement, steel, and chemicals). One of the main reasons for the inefficiency of heavy-industry-intensive provinces is that heavy industry emits too many pollutants and CO_2. In the process of promoting high-quality development and carbon neutrality, energy and raw materials will be low-carbon and green, which will greatly reduce the pollutant and CO_2 emissions of heavy industry, and the declining value will be much higher than that of other industries.

The economic and social system has both supply and demand, and they complement each other. In April 2020, in view of the new development environment, China proposed to build a new development pattern with the domestic cycle as the main body and the domestic and international dual cycles promoting each other [45]. In May 2020, China proposed to deepen the SSR, give full play to the advantages of my country's super-large market and the potential of domestic demand, and build a new development pattern in which the domestic and international dual cycles promote each other [46]. In this context, China's demand-side management and the SSR are required to be coordinated in reality. The release of China's consumption potential helps to better resolve problems such as overcapacity on the supply side. The demand for high-quality, high-tech, and high-value-added products will increase, thereby driving the development of supply-side high-tech and value-added industries. China will respond to the short-term increase in total demand by deepening the SSR and ensuring high-quality supply. In addition, the supply side should speed up the development of high-tech and high-value-added industries to meet the continuous increase in demand for high-tech and high-value-added products on the demand side.

5. Conclusions and Policy Implications

This study is the first to analyze the effect of implementing SSR in China's provincial industrial sector, especially the differences between provinces and the reasons behind them, which not only fills the gap of current research on this problem but also provides methodological ideas for expanding this research. In addition, this research can provide a reference for China's continued deepening of the SSR and policy formulation to promote high-quality development and carbon neutrality goals and provide a basis for expanding this research question. The conclusions of this study are as follows:

(1) The positive effects of China's SSR implementation have already emerged, at least in the industrial sector in most provinces. This positive effect is mainly reflected in the fact that the implementation of measures such as reducing overcapacity has promoted the technological innovation of enterprises. In addition, the SSR has not been particularly manifested in improving management-level and resource allocation efficiency, which may be the future SSR needs to be strengthened.

(2) Even after two years of SSR, the PTE of most economically underdeveloped provinces in China is still extremely low, which shows that in the future SSR, it is more necessary to improve the management level. China's current level of enterprise management is also behind that of Japan, the European Union and the United States, and other countries or organizations.

Based on the above two conclusions and the discussion in Section 4.4, we put forward the following two suggestions:

(1) Deepening the SSR is the main line of economic and social development during the 14th Five-Year Plan period. However, with the deepening of reform, the focus of SSR should be adjusted. It should focus on improving the management level of enterprises and optimizing the allocation of resources to improve the production efficiency of the whole society. This requires the Chinese government to speed up market-oriented construction, strengthen the competition mechanism of enterprises, and guide enterprises to improve their management levels.

(2) In the new development stage, especially in the context of China's high-quality development and carbon neutrality goals, the SSR has been given new connotations.

In addition to the traditional "three removals, one supplement, and one drop", SSR needs to incorporate the requirements of green and low-carbon development. To put it another way, future policy formulation to promote China's high-quality development and carbon neutrality goals can be achieved by gradually giving new content to the SSR policy, at least in the short term. In this way, a benign continuation of the SSR policy can be achieved.

This research enriches the research regarding China's SSR. However, the results cannot be used to analyze the impact of the SSR on an industry in various provinces. The next research direction of this study would be to further analyze the SSR's progress in the iron and steel industries in various provinces and then propose the focus of future SSR for various provinces at the industry level.

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