Calculation of China's environmental efficiency based on the SBM model with undesirable outputs

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Abstract

With the rapid development of china's economy, the environment of china faces some prominent questions, industrial pollution, water pollution, serious smog and other problems continue get worse, therefore, it's very significant to analyse China's regional environmental efficiency. This paper mainly measure china's regional environmental efficiency by SBM model with undesirable outputs, and according to the calculation results, we find that the overall average level of china's environment efficiency is low, and the gap between different provinces is large. Finally, this article gives some policy proposal about how to increase china's environmental efficiency and reduce pollution emission.

Keywords: Environmental Efficiency, SBM Model, Undesirable Outputs

1 Introduction

Some countries have taken a lot of ways to solve environmental problems, but Global warming, water pollution and other problems are becoming worse, Environmental problems have become very serious in China, this not only affects people's health, but also seriously affected the china's sustainable development plan. On 12 August 2009, the state council approved a plan entitled "Environmental Impact Assessment Ordinance", This evaluation method has a high value in strategic planning. However China's environmental assessment is only just beginning, There are many deficiencies in the practical application, Therefore, establishing a set of scientific management evaluation method, improving the utilization of resources, reducing the emissions of waste materials will be the theme of environmental science at present, Since China is a major carbon dioxide and other greenhouse gas emission producer, China's environmental policy greatly impacts the balance of the global climate. In order to achieve the goal of energy conservation and emissions reduction, the provinces will require coordination, on the other hand, to determine the environmental efficiency of different regions accurately requires scientific and systematic environmental efficiency evaluation research. So that it can reflect environmental performance differences and gaps in different regions of China, each area can improve the environmental performance by using an objective reference standard. In the past few decades, many scholars studied the econometric analysis model and method to solve complex environmental problems. Among them, Environmental efficiency of computing problem has become a very important topic for many scholars. However, how to find a more effective method to provide some quantitative information of performance evaluation and policy analysis remains an interesting area that should be thoroughly studied.

The structure of this article is as follows. Section 2 is a literature review. Section 3 introduces environmental efficiency evaluation model, data and indexes. Section 4 is the conclusions from the environmental efficiency values of china's provinces. And some relevant Suggestions are given in Section 5.

2 Literature review

DEA was proposed by Charns [1] and is a non-parametric statistical method based on linear programming model to measure the efficiencies of decision-making units. Subsequently, Fare developed the method and combined it with environmental production technology [2]. DEA based on the concept of ''Relative Efficiency Evaluation'', is the systematic analysis method using relative theory and a model of operational research to evaluate the relative efficiency of decision making units according to the multiple index input and output data. In recent years, DEA has gained great popularity in measuring the energy and environment efficiency at the macro-economy level. Zhou et al. summarized more than 100 DEA applications in energy and environment policy and they pointed out DEA model is characterized by its reference technology and efficiency measure [3]. Because China has already become the world's second largest economy and the largest Co emitter, it has become the focus with researchers studying the energy issue from the macro-economy perspective. Examples of such studies include [4–9], and so on. In the empirical part, DEA and

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the corresponding extended model have been widely used in the energy and environmental efficiency evaluation. In the micro family part, Barba-Gutiérrez [10] analyses the environmental efficiency of household appliances and electronic equipment [10]. In the industrial part, Azadeh et al. [11], separately using the DEA model and the comprehensive model based on DEA, have explored both the environmental and energy efficiency of Iran's power transmission system and more than 100 countries' power production systems [11]. Mukherjee [12] has built a non-radial efficiency calculation method based on the DEA model, and Riccardi et al. [13], on the basis of the non-radial efficiency model, take undesirable outputs into consideration in the energy efficiency calculation. Mukherjee [12] and Riccardi et al. [13] separately study the energy efficiency of India's manufacturing industry and the global cement industry. In the macroscopic part, Chiu and Wu [14] have analysed the environmental efficiency of 27 Chinese provinces (municipality or autonomous regions) with the DEA model. With the enhancement of environmental protection consciousness [15], some environmental issues such as air pollution and hazardous waste have been widely recognized as a social issue So, how to correctly measure environmental efficiency considering undesirable output becomes a hot topic.

3 Methodology and models construction

By constructing DEA models decision makers cannot only optimally design their systems, but also determine their optimal budgets. Deviation may appear in measurement of efficiency if CCR model is directly used and slack effect of input factors is neglected. Hence, Tone suggested a SBM model considering slack measurement, which is neither radial nor oriented, making it effective in remedying disadvantages of CCR and BCC models.

Traditional CCR model is expressed as follows:

$$\min \theta ,$$

$$\text{s.t. } \sum_{j=1}^{n} \alpha_j x_{ij} + s^- = \theta x_0, i = 1, 2, \cdots m$$

$$\sum_{j=1}^{n} \alpha_j y_{rj} - s^+ = y_0, r = 1, 2, \cdots s ,$$

$$\alpha_j, s^-, s^+ \geq 0, j = 1, 2, \cdots n$$

where x_{ij} is the inputs, y_{ij} is the outputs, x_0 and y_0 represent the input and output of DMU_0 respectively. s^- is the slacks of inputs; s^+ is the slacks of outputs. When the optimal value θ^0 =1, DMU_0 can be called as a weakly efficient DMU. When the optimal value θ^0 = 1 and $s^- = s^+ = 0$, DMU_0 can be called as an efficient DMU. If a new constraint, $\sum \alpha = 1$, is added in the model, we can gain the BCC model .

We further suppose that there are n DMUs with one input vector X and two output vectors for each DMU; desired output is Y^g and undesirable output is Y^b. The three vectors are defined as:

$$X = (x_1, x_2, \cdots x_n) \in R^{m \times n}, x_i \in R^m ,$$

$$Y^g = (\mathrm{x}_1^g, \mathrm{x}_2^g, \cdots \mathrm{x}_n^g) \in R^{s_1 \times n}, \mathrm{y}_i^g \in R^{s_1} ,$$

$$Y^b = (\mathrm{x}_1^b, \mathrm{x}_2^b, \cdots \mathrm{x}_n^b) \in R^{s_2 \times n}, \mathrm{y}_i^b \in R^{s_2} .$$

Here, $x_i > 0, \mathrm{y}_i^g > 0, \mathrm{y}_i^b > 0$. With constant return to scale, possible production volume is defined as P:

$$P = \left\{ (\mathrm{x}_i, \mathrm{y}_i^g, \mathrm{y}_i^b) / \mathrm{x}_i \geq X\lambda, y_i^g \leq Y^b\lambda, y_i^b \geq Y^b\lambda, \lambda \geq 0 \right\} .$$

So, SBM model can be expressed as:

$$\min \frac{1 - \frac{1}{m}\sum_{i=1}^{m}\frac{s^-}{x_{i0}}}{1 + \frac{1}{s_1 + s_2}\left(\sum_{r=1}^{s_1}\frac{s_r^g}{y_{r0}^g} + \sum_{r=1}^{s_2}\frac{s_r^b}{y_{r0}^b}\right)} , \quad (1)$$

$$\text{s.t. } x_0 = X\lambda + s^- ,$$

$$y_0^g = Y^g\lambda - s^g ,$$

$$y_0^b = Y^b\lambda + s^b ,$$

$$\lambda \geq 0, s^- \geq 0, s^g \geq 0, s^b \geq 0 .$$

Thereinto, λ is weighing vector; s^- is slack variable of input, representing surplus of input; s^g , s^b are slack variables of output, representing inadequacy of output and surplus of undesirable output. Target function ρ' strictly descends in relation to s^- , s^g , s^b and $0 \leq \rho' \leq 1$. For a specific DMU, if $\rho' < 1$, the DMU is inefficient; if $\rho' = 1$ and $s^- = s^g = s^b$, the DMU is efficient. Unlike traditional CCR and BCC models, SBM model directly adds slack variables into target function, which cannot only solve the problem of slack in input and output but measure efficiency with undesirable output. As slack in input and output is considered in SBM model, Tone concluded that only when a DUM is efficient based on CCR model, it will be efficient based on SMB model with efficiency value in CCR bigger than or equal with that in SBM. In addition, SBM model is neither radial nor oriented, making it possible to avoid deviation caused by radial nor orient. Accordingly, nature of efficiency measurement can be better presented with this model.

This paper mainly investigates environmental efficiency conditions of the whole of China and each province under the pollution situation. Therefore, by using the related literature, we take the panel data of mainland China's 29 provinces from 2000 to 2012 as a sample.

For the input indicators, modern western economics considers capital, labour and land as the most important production input elements. According to its general meaning in economics and the majority of research, capital stock at constant prices is considered to be a good proxy indicator for capital investment. As Chinese official statistic bureaus have not publicly announced data of capital stock, it was estimated by using perpetual inventory method and expressed as follows:

$$K_t = K_{t-1}(1-\delta_t) + I_t ,$$

there into, K_t denotes capital stock in the year t; I_t denotes investment in the year t; δ_t denotes depreciation rate of fixed assets in that year.

It is generally thought that the earlier the benchmark is, the smaller the error will be in the long-term estimation. Therefore, in this article, we began our estimation from the year 1958. First, the sum of fixed assets in each year for each province was converted into an invariable value in 1958 by using an implicit deflator index. Then capital stock was calculated by using a basic equation of perpetual inventory method according to the benchmark of capital stock and depreciation rate set in advance. The value of capital stock for each province in our article is calculated on the basis of an invariable value in 1958.

$$\textit{Capital} \text{ stock in 1958} = \frac{\textit{Sum} \text{ of stock in 1959}}{\textit{Depreciation} \text{ rate+AIRIFA}} ,$$

There into, AIRIFA means average increasing rate of investment in fixed assets during 1958–1962; depreciation rate is universally 10.12% for all provinces and relevant data are from Statistic Yearbook of China for each year.

The number of employed persons at each year's end in different provinces instead of the labour force indicators is selected; because each province's land is nearly constant and cannot reflect their differences, we choose energy consumption, which has a closer connection with the production process instead of the land indicators. Generally speaking, the production process is the course to cost resources for outputs. The criterion to evaluate DMU's efficiency is fewer inputs and more outputs, which provides the DMU's greater effectiveness. However, the production process products not only include the expected outputs, but also outputs such as pollutants, which people do not expect. Therefore, we divided outputs as desirable and undesirable. The GDP of different provinces will be used to present the desirable output. There is less detailed data of pollutants such as CO_2, SO_2 and NO_2 in China. The emission of three wastes (industrial wastewater, gas and solid) in each province will be used as the similar proxy variables on behalf of the undesirable output. The data comes from the China Statistical Yearbook, China Energy Statistical Yearbook, and China Environment Statistical Yearbook, published by the National Bureau of Statistics of China. The basic statistical characteristics of specific input–output data are shown in Table 1.

4 China's environmental efficiency

Environmental efficiency of each province from 2001 to 2012 is calculated by using Equation (1) and the results are shown in Table 2.

In line with convention, China is divided economically into three main regions: the East, the Central, the West. The East region includes: Beijing, Fujian, Guangdong, Hebei, Jiangsu, Shandong, shanghai, Tianjin and Zhejiang, Heilongjiang, Jilin and Liaoning; the Central includes: Anhui, Henan, Hubei, Hunan, Jiangxi and Shanxi; the West includes: Gansu, Guangxi, Guizhou, Inner Mongolia, Ningxia, Qinghai, Shanxi, Chongqing, Sichuan, Xinjiang and Yunnan.

Environmental efficiency of the three regions is different greatly. The average value of the East is about 0.634, the Central is about 0.245 and a litter better of 0.323 for the West. The east has advanced technology and higher management level, And investment in terms of environmental management is quite huge, always controlling pollution at very low levels. Though the West drops behind economically, Western industry is at a stage of development, leading to relatively low emissions, in the west of the environment is better than the central, because the central of the low level of economic and the environmental pollution is serious.

TABLE 1 Descriptive statistical characteristics of input and output variables

variable	Input index			Output index	
	Capital x_1	Labour x_2	Energy x_3	GDP y^g	Waste y^b
Mean	2357.14	2265.56	6613.43	5043.89	7128.68
Median	1323.46	1879.67	5234.76	2879.76	4758.65
Maximum	20293.33	6348.32	34357.87	43879.45	56456.34
Minimum	27.18	210.00	176.98	67.46	112.87
Std.dev.	1467.94	1345.65	4367.76	3047.86	5423.65
Skewness	2.5472	0.6566	1.9235	2.6776	2.45
Kurtosis	11.7648	2.7453	7.5465	14.3424	12.5436

Note: Each sample has 600 observations, for the panel data includes 5 indicators of 29 provinces from 2001 to 2012

TABLE 2 Values of environmental efficiency in China (2001–2012)

year	2001	2002	2003	3004	2005	2006	2007	2008	2009	2010	2011	2012
Beijin	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Tianjin	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Hebei	0.486	0.464	0.442	0.428	0.405	0.394	0.394	0.364	0.351	0.342	0.332	0.319
Shanxi	0.241	0.250	0.262	0.242	0.224	0.220	0.230	0.223	0.222	0.221	0.270	0.228
Innermongolia	0.357	0.336	0.335	0.325	0.331	0.268	0.243	0.217	0.204	0.198	0.221	0.222
Liaoning	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Jilin	0.476	0.454	0.472	0.494	0.471	0.442	0.415	0.398	0.364	0.323	0.313	0.287
Heilongjiang	0.336	0.446	0.382	0.391	0.375	0.392	0.381	0.405	0.413	0.391	0.384	0.342
Shanghai	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Jiangsu	0.558	0.535	0.524	0.498	0.483	0.454	0.412	0.375	0.364	0.362	0.364	0.360
Zhejiang	0.735	0.692	0.653	0.612	0.604	0.562	0.508	0.512	0.504	0.409	0.472	0.468
Anhui	0.296	0.289	0.298	0.286	0.262	0.277	0.274	0.262	0.264	0.247	0.257	0.245
Fujian	1.000	1.000	1.000	1.000	1.000	1.000	0.586	0.667	0.715	0.689	0.654	0.653
Jiangxi	0.241	0.233	0.214	0.212	0.197	0.183	0.175	0.162	0.158	0.152	0.152	0.149
Shandong	0.540	0.524	0.463	0.451	0.423	0.412	0.381	0.354	0.343	0.342	0.318	0.317
Henan	0.321	0.324	0.317	0.310	0.297	0.282	0.263	0.251	0.237	0.211	0.208	0.198
Hubei	0.362	0.368	0.367	0.363	0.365	0.346	0.311	0.333	0.329	0.321	0.319	0.318
Hunan	0.322	0.384	0.416	0.418	0.393	0.332	0.289	0.324	0.341	0.312	0.313	0.298
Guangdong	0.456	0.418	0.401	0.386	0.364	0.354	0.346	0.341	0.342	0.347	0.329	0.318
Guangxi	0.376	0.378	0.378	0.346	0.338	0.312	0.246	0.298	0.307	0.284	0.303	0.286
Hainan	0.758	0.748	0.752	0.682	0.683	0.645	0.665	0.752	0.723	0.741	0.698	0.701
Sichuan	0.158	0.157	0.164	0.165	0.560	0.155	0.156	0.144	0.195	0.144	0.195	0.185
Chongqing	0.156	0.163	0.156	0.163	0.423	0.153	0.152	0.142	0.185	0.142	0.186	0.187
Guizhou	0.128	0.131	0.134	0.128	0.125	0.114	0.112	0.113	0.124	0.116	0.118	0.132
Yunan	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Shaanxi	0.348	0.356	0.339	0.325	0.302	0.283	0.264	0.275	0.276	0.256	0.248	0.242
Gansu	0.324	0.324	0.312	0.306	0.298	0.267	0.256	0.248	0.242	0.232	0.237	0.237
Qinghai	0.262	0.225	0.226	0.220	0.223	0.216	0.198	0.176	0.165	0.158	0.163	0.154
Ningxia	0.406	0.398	0.385	0.395	0.346	0.293	0.254	0.246	0.253	0.234	0.236	0.250
Xinjiang	0.298	0.293	0.284	0.269	0.256	0.243	0.227	0.206	0.207	0.198	0.192	0.190

Data are calculated according to Equation (1) by using collected data

Environmental efficiency of each province from 2001 to 2012 Values of environmental efficiency are generally small with a downtrend for most provinces. Shanghai, Beijing and Tianjin's efficiency value has always been 1, making them on the frontier. At the same time, they have become the standard of the other provinces to measure efficiency value, The value for Fujian have been 1 for 6 years from 2001–2006; but it fail to reach the frontier later though it is relatively big. This change is caused by too much waste water discharge according to analysis of redundancy rate, Efficiency values are the smallest for Guizhou, Jiangxi, Qinghai ,Sichuan and Chongqing with average value smaller than 0.2, far from the frontier. Referring to Beijing, Tianjin, Shanghai, Yunnan and Liaoning, polluting emission in Guizhou, Jiangxi, Qinghai and Sichuan can be reduced by about 80% with the same input and output. Analysis shows that in front of the value, there is a huge difference among various provinces, and the potential of reducing polluting emission is bigger for provinces with smaller values. For Zhejiang, Shandong, Jiangsu and Guangdong, Because of the high energy consumption and pollution emissions, their efficiency values decrease obviously though these provinces are economically developed areas. One more point should be stated clearly. Efficiency value measured in our article is just a comparative index, meaning provinces on the producing frontier enjoy some advantages. There absolutely exists room of reducing polluting emission for them. In the exploration and the application of environmental protection technology, China is still a long way to go. High efficiency value of provinces has an obligation to improve environmental protection and reduce pollution emissions.

5 Conclusions

According to the above analysis, we can give some advice on improving the efficiency of China's environmental protection: (1) Continue to give top priority to the east, using The advantage of the developed economy, energy conservation and emissions reduction to change the industrial structure, To improve the technology of industry, productivity, and reasonable development of the tertiary industry, To improve the ratio of the third industry in the national economy, to build a resource conservation and environmentally friendly society. (2) According to regions' different levels, making out the energy conservation and emissions reduction goals and policies, focus on the central and western regions, where there is more room to improve. With a low environment efficiency to balance the regional difference. Since the west development policy, the economic development of the western is good, need to increase the area in terms of production technology research, and communicate with other regional cooperation. And at the same time, Under the background of the rapid development in the Midwest, central also need to accelerate the industrial innovation, optimize the industrial structure and the allocation of resources, improve efficiency, so as to accelerate the economic development, realize the central and western regions of the strategic significance of ecological environment for China's sustainable development. (3) To strengthen environmental control, according to the domestic and international situation, making energy conservation and emission reduction policy, coordinate relationship between economic development and environmental protection, to guide the local government to improve environmental efficiency. (4) Accelerate the development of science and technology, especially in the energy saving of high technology innovation to give more policy support, ensure that the new technology faster and more widely applied to each region, industry, and the production process, as well as ensuring the environmental efficiency steadily increases with rapid economic development.

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