Chapter 10

Comparing the Dynamic Analysis of Energy Efficiency in China with Other Countries

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Additional information is available at the end of the chapter

http://dx.doi.org/10.5772/48589

1. Introduction

The development of world economy is closely related with energy consumption. According to the economics research by Department of Agriculture of the U.S., since 2000, the energy consumption quantity begins to rise sharply at an average annual growth rate of 2.5% which approximates with the global real GDP (gross domestic product) growth. In China, the second largest economy in the world, this index increases by 15.1% in 2004. Excessive energy consumption, together with the environmental pollution, has become a huge threat to the sustainable development of human beings. Thus, the continuous pursuing for higher energy utilization has drawn the attention of many researchers.

There are three categories of indices to evaluate energy utilization summarized by Ang[1] which are thermodynamic indicators, physical-based indicators, and monetary-based indicators. Different with the first two indicators, outputs in monetary-based indicators are measured in form of currency. This causes monetary-based indicators popularly used in measuring energy efficiency of various levels, not only the common production process at the micro-level but also the comparison between countries at the macro-level.

Ang [1] introduces some key indices belonging to the category of monetary-based indicators. Energy intensity (EI), which is defined as the quotient of total energy consumption divided by total output (GDP or GNP), is used to estimate one's energy efficiency roughly[1]. Energy coefficient is another index referring to the quotient of growth rate of total energy consumption divided by growth rate of total output, which is usually applied in comparison among various countries or regions [2]. However, the stability of energy coefficient is very poor, especially when the growth rate of one country's GDP approaches to 0. Benefit for its clear definition, simple calculation and easily improvement, EI becomes the most frequently-used index in energy efficiency evaluation from both points of practice and research.

Most of literatures studying energy efficiency adopt energy intensity to analyze energy utilization efficiency, for instance, Howarth et al. [3] and Greening et al. [4], both of which are quoted frequently by other researchers. However, for simplicity, total energy consumption used in EI calculation only considers the sum of all kinds of energy consumption. EI neglects the structure of energy consumption, that's why the index may estimate the energy efficiency inaccurately. Different energy storage capacities and consumption habits make energy consumption structure to be an indispensable influence factor in evaluation. In order to deal with this problem, Xu and Liang [5] introduced a weighted energy intensity model based on data envelopment analysis to evaluate the energy efficiency considering energy consumption structure.

Data envelopment analysis (DEA), a popular approach to evaluate the relative efficiency of homogenous decision making units (DMU) with multiple inputs and multiple outputs[6], has been widely used in the energy efficiency analysis and gained a lot of research achievement [7]. For example, in recent literatures, Mohammadi et al. [8] used DEA approach to evaluate energy efficiency of kiwifruit production in Iran. Rao et al.[9] developed an improved DEA model to analyze energy efficiency and energy savings potential in China. Bian and Yang [10] summarized several DEA models for measuring the energy efficiency and proposed an extended Shannon-DEA method to define a comprehensive concept of energy efficiency.

However, EI index based on DEA concentrates on the transforming degree of energy consumption to GDP or other economic statistical data, and ignores the function of non resource inputs such as labor and capital stock which also play an essential role during the production process. Boyd and Pang [11] introduced the concept of total factor energy efficiency (TFEE) and proposed a model to estimate the linkage between energy efficiency and productivity of the glass industry. References [12] and [13, 14] developed a series of models in estimating total factor energy efficiencies of 29 regions of China and Japan.

Except for using DEA model to analyze the energy efficiency at a given time, this chapter intends to investigate the dynamic change of energy efficiency over periods by adopting Malmquist production index (MPI) technique. First applied to study on the consumers' behavior, after improved for many years, MPI approach deserves high praise in input-output analysis for the reason as follows: (1) no need for the price of input or output; (2) no need for the assumption of behavior pattern; (3) to get more intensive result of dynamic change easily[15]. MPI divides the total production growth rate into two parts, catch-up effect and frontier-shift effect, from which the cause of the change in energy efficiency can be clarified[16].

The current chapter tries to compare the total factor energy efficiencies of 48 countries all over the world in 2003 and analyze the dynamic change in total factor energy efficiencies of provinces of China over the period of 2000-2003 by the proposed model. The rest of this chapter is organized as follows. In Section 2, we introduce several methods for measuring the total factor energy efficiency and the dynamic change based on DEA and MPI technique. Section 3 shows how to use the proposed approach in analyzing the energy efficiency of 48 countries in 2003 and section 4 presents a dynamic example of total factor energy efficiency estimation of 30 provinces in china. Section 5 concludes this chapter.

2. Methodology

2.1. Energy efficiency considering energy structure based on DEA model

Suppose that there are n homogenous decision making units (DMU) to be evaluated, denoted by DMUj (j = 1, 2, …, n). Each DMU consumes m type of energy inputs xij (i = 1, 2, …, m) to produce s types of outputs yrj (r = 1, 2, …, s).

Xu and Liang introduced weighted energy intensity model (WEI) based on DEA to evaluate the energy efficiency considering energy structure. Energy efficiency of DMU_0 is obtained by the following fractional programming:

$$\begin{aligned} \max\ & h_0 = \frac{\sum_{r=1}^{s} \mu_r y_{r0}}{\sum_{i=1}^{m} v_i x_{i0}} \\ s.t.\ & \frac{\sum_{r=1}^{s} \mu_r y_{rj}}{\sum_{i=1}^{m} v_i x_{ij}} \le 1, \quad j = 1,2,\dots,n \\ & \mu_r, v_i \ge 0, \quad r = 1,2,\dots,s;\ i = 1,2,\dots,m. \end{aligned} \tag{1}$$

In the empirical example, xij stand for all kinds of energy consumption like crude oil, natural gas, coal and so on while yrj are outputs. The vector of vi stands for the weights of the energy consumption xij which represents the energy structure. In addition, the vector of μr is the weight of the output yrj. According to DEA technique, DMU_0 is efficient if there is a parameter bundle (vi, μr) making the target value equal to 1. The production frontier constituted by all of the efficient DMUs suggests an improvement direction to the non-efficient DMUs.

Halkos & Tzeremes have noticed that the scale of countries has influence on the energy efficiency especially when estimating the various countries and regions[17]. Some small countries could be efficient under the condition of variable return-to-scale (VRS) as there is less restrictive[18]. Banker et al.[19] improved an extension based on the variable return-to-scale assumption by adding a convexity constraint.

Here we transform Programming (1) into an integral linear programming and add the VRS assumption. Then we obtain the following program:

$$\begin{aligned} \min\ & \theta \\ s.t.\ & \sum_{j=1}^{n} \lambda_j x_{ij} \le \theta x_{i0}, \quad i = 1,2,\dots,m. \\ & \sum_{j=1}^{n} \lambda_j y_{rj} \ge y_{r0}, \quad r = 1,2,\dots,s. \\ & \sum_{j=1}^{n} \lambda_j = 1, \\ & \lambda_j \ge 0, \quad j = 1,2,\dots,n. \end{aligned} \tag{2}$$

2.2. Total factor energy efficiency based on DEA model

The concept of total factor energy efficiency investigates deeply into the energy consumption and production procedure and takes the non-resource inputs into account. As some representative examples, capital stock and labor are usually included. Following program is used to evaluate the total factor energy efficiency:

$$\begin{aligned} \min \quad & \theta \\ s.t. \quad & \sum_{j=1}^{n} \lambda_j x_{ij} \le \theta x_{i0}, \quad i = 1,2,\ldots,m. \\ & \sum_{j=1}^{n} \lambda_j z_{tj} \le \theta z_{t0}, \quad t = 1,2,\ldots,p. \\ & \sum_{j=1}^{n} \lambda_j y_{rj} \ge y_{r0}, \quad r = 1,2,\ldots,s. \\ & \lambda_j \ge 0, \qquad j = 1,2,\ldots,n. \end{aligned} \tag{3}$$

Here ztj (t = 1, 2, …, p) stands for the non-resource inputs of DMUj. Adding the VRS assumption turns Model (3) into the following linear programming:

$$\begin{aligned} \min \quad & \theta \\ s.t. \quad & \sum_{j=1}^{n} \lambda_j x_{ij} \le \theta x_{i0}, \quad i = 1,2,\ldots,m. \\ & \sum_{j=1}^{n} \lambda_j z_{tj} \le \theta z_{t0}, \quad t = 1,2,\ldots,p. \\ & \sum_{j=1}^{n} \lambda_j y_{rj} \ge y_{r0}, \quad r = 1,2,\ldots,s. \\ & \sum_{j=1}^{n} \lambda_j = 1, \\ & \lambda_j \ge 0, \qquad j = 1,2,\ldots,n. \end{aligned} \tag{4}$$

2.3. Total factor energy efficiency based on Malmquist production index

The above sections discuss the efficiency evaluation at a given time while this section presents the efficiency evaluating model during a period. Malmquist production index (MPI) is widely applied in measuring the dynamic variation trend of input-output efficiency by dividing the total efficiency into two parts, catch-up effect and frontier-shift effect [20]. Catch-up effect detects whether the efficiency of DMU makes progress during the period. If the numerical value of catch-up effect is more than 1, then we can make sure that the technical efficiency of DMU gets improvement and DMU is closer to the production frontier. Frontier-shift effect is used to assess the technique advancement which is measured by the transform degree of production frontier at different time-points. If the numerical value of frontier-shift effect is more than 1, it means the production technique of the latter is better than that of the former.

We assume that the production possibility set at time t, denoted by St, includes all of the feasible production bundles, input xt and output yt. For each time-point t, we have

$$S^t = \left\{ (x^t, y^t) : x^t \text{ can produce } y^t \right\}$$

And the input distance function at time t is

$$D_i^t(x^t, y^t) = \sup\{\delta : (x^t / \delta, y^t) \in S^t\} = \frac{1}{\inf\{\delta : (\delta x^t, y^t) \in S^t\}}$$

Following Färe et al. [21] and Boussemart et al. [22], the catch-up effect can be defined as

$$catch-up = \frac{D_i^{t+1}(x^{t+1}, y^{t+1})}{D_i^t(x^t, y^t)}$$

Where $D_i^{t+1}(x^{t+1}, y^{t+1})$ means the efficiency of DMU $\left(x^{t+1}, y^{t+1}\right)$ at time $t+1$ and $D_i^t(x^t, y^t)$ means the efficiency of DMU $\left(x^t, y^t\right)$ at time t.

The frontier-shift effect is defined as

$$frontier-shift = \sqrt{\frac{D_i^t(x^t, y^t)}{D_i^{t+1}(x^t, y^t)} \times \frac{D_i^t(x^{t+1}, y^{t+1})}{D_i^{t+1}(x^{t+1}, y^{t+1})}}$$

Where $D_i^t(x^{t+1}, y^{t+1})$ means the efficiency of DMU $\left(x^{t+1}, y^{t+1}\right)$ at time t and $D_i^{t+1}(x^t, y^t)$ means the efficiency of DMU $\left(x^t, y^t\right)$ at time $t+1$.

The Malmquist production index can be measured as follows:

$$MPI = catch\text{-}up \times frontier\text{-}shift$$

We notice that there need four efficiencies to obtain the MPI and two of which can be obtained by the linear program (3). The other two efficiencies, $D_i^t(x^{t+1}, y^{t+1})$ and $D_i^{t+1}(x^t, y^t)$, can be measured by the following two models.

$$\begin{aligned} & \min\ \theta \\ & s.t.\quad \lambda_j x_j^{t+1} \le \theta x_0^t, \\ & \qquad \lambda_j z_j^{t+1} \le \theta z_0^t, \\ & \qquad \lambda_j y_j^{t+1} \ge y_0^t, \\ & \qquad \textstyle\sum_{j=1}^n \lambda_j = 1, \\ & \qquad \lambda_j \ge 0,\ j = 1, 2, \ldots, n. \end{aligned} \tag{5}$$

$$\begin{aligned} &\min\ \theta \\ &s.t.\quad \lambda_j x_j^t \le \theta x_0^{t+1}, \\ &\qquad \lambda_j z_j^t \le \theta z_0^{t+1}, \\ &\qquad \lambda_j y_j^t \ge y_0^{t+1}, \\ &\qquad \textstyle\sum_{j=1}^{n} \lambda_j = 1, \\ &\qquad \lambda_j \ge 0,\ j = 1,2,\ldots,n. \end{aligned} \tag{6}$$

3. A comparative analysis of energy efficiency of 48 countries

In this chapter, energy efficiency analysis of 48 countries in 2003 is illustrated. The major countries and regions all over the world are included in our consideration such as the United States, China, Russia, Japan and so on. Primary energy consumption includes oil, natural gas, coal, nuclear energy and hydropower. We incorporate oil and natural gas consumption as the first part of energy input. Nuclear power and hydropower are incorporated as the second part of energy input. Coal is the third input. Labor and capital stock are adopted as the non-resource input. Gross Domestic Product (GDP) is the only output.

The data on energy input are collected from World Petroleum Yearbook (2004). GDP and labor are obtained from the World Development Indicators database (2003). Due to the unavailability on the data of capital stock of some countries, we use the index of adjust savings after consumption of fixed capital as a substitute. The data is available from the website of World Bank. All of the data collected are summarized in Table 1.

Category	Indicators	Max	Min	Mean
Energy inputs	Oil & natural gas	1481.1	5.3	105.62
	Nuclear power & hydropower	799.7	0.1	51
	Coal	242.8	0.2	22.27
Non-energy inputs	Labor	129483.9	362.1	10208.44
	Capital stock	13012	8.1	933.06
Output	GDP	109486	99	6828.9

* The units of data on energy inputs are all million tones oil equivalents. Labor is expressed in units of 10-thousand persons. Capital stock is stated in units of 100-million USD. GDP is described in units of 100-million USD.

Table 1. Summary of inputs and output

Table 2 shows the results of energy efficiency considering energy structure measured by model (2). Countries in column 2 are ranked by GDP. The third column represents energy efficiency considering energy structure. Results indicate that: (1) there are 10 efficient DMUs including US, Japan, Italy and so on; (2) 21 countries' energy efficiency scores lie on the interval of 0.5-1 and the typical countries are Britain, Germany, Mexico, etc; (3) the energy efficiency scores of the rest 17 countries are at very low level, less than 0.5; (4) the return-to-scale situation of most developed countries is in decreasing stage while in contrast many developing countries behave increasing returns to scale.

No.	Country	WEI-VRS	Rank	RTS
1	United States	1.0000	1	D
2	Japan	1.0000	1	D
3	Germany	0.9086	12	D
4	Britain	0.9969	11	D
5	France	1.0000	1	D
6	Italy	1.0000	1	D
7	China	0.3391	40	D
8	Canada	0.3471	38	D
9	Mexico	0.7755	18	D
10	Korea	0.3359	41	D
11	India	0.3526	36	D
12	Australia	0.8422	16	D
13	Netherlands	1.0000	1	D
14	Brazil	0.2938	42	D
15	Russian Federation	0.0707	48	D
16	Switzerland	1.0000	1	C
17	Sweden	0.8560	15	I
18	Austria	0.7669	19	D
19	Turkey	0.3469	39	D
20	Norway	0.8601	14	I
21	Poland	0.6479	22	D
22	Indonesia	0.2256	45	D
23	Greece	0.5793	26	D
24	Finland	0.7047	21	I
25	South Africa	0.4902	32	I
26	Ireland	1.0000	1	C
27	Portugal	0.5838	24	I
28	Thailand	0.1894	46	I
29	Iran	1.0000	1	C
30	Argentina	0.4893	33	I
31	Malaysia	0.2928	43	D
32	Czech Republic	0.5073	30	I
33	Hungary	0.5485	27	I
34	Egypt	0.5417	28	I
35	Pakistan	0.2818	44	I
36	Philippines	0.5805	25	I

37	New Zealand	0.7114	20	I
38	Columbia	0.5025	31	I
39	Chile	0.4777	34	I
40	Peru	0.8972	13	D
41	Romania	0.3488	37	I
42	Bangladesh	1.0000	1	C
43	Ukraine	0.1096	47	I
44	Slovakia	0.6364	23	I
45	Kazakhstan	0.5090	29	I
46	Bulgaria	0.8084	17	I
47	Lithuania	1.0000	1	D
48	Uzbekistan	0.3637	35	I

* D, I and C indicate decreasing, increasing and constant return-to-scale respectively.

Table 2. Energy efficiencies of 48 countries considering energy structure

It is particularly pointed out that the energy efficiency of China is only 0.3394 which is the worst among the top 10 countries ranked by GDP. The information of the input/output shown in Table 3 release that there are two reasons for that. First, the technical efficiency of energy consumption of china is lower, compared with Italy for example which has approximate output. Second, by comparison with 10 efficient countries, China has an improper construction of energy consumption that mainly relies on coal resource. Considering the heavy environmental pollution with coal's burning, adjusting the structure of energy consumption is imperative.

No.	Country	GDP	Oil & Gas	Nuclear & hydropower	Coal
1	Japan	43009	317.6	112.2	75
2	Ireland	1537	12.1	1.6	0.2
3	Bangladesh	519	15.2	0.4	0.2
4	Netherlands	5115	79.9	9.2	0.9
5	France	17576	133.6	12.4	114.6
6	Italy	14683	156.6	15.3	10
7	Iran	1371	126.4	0.7	2
8	Switzerland	3201	14.7	0.1	14.5
9	Lithuania	182	5.3	0.1	3.7
10	United States	109486	1481.1	573.9	242.8
11	China	14170	304.7	799.7	73.8

* The units of data on energy inputs are all million tones oil equivalents. GDP is described in units of 100-million USD.

Table 3. Input/output of 10 efficient countries and China

Table 4 represents total factor energy efficiency calculated by model (3) & (4). Countries in column 2 are ranked by GDP. Column 3 and 5 show two kinds of results due to the different setting-ups of return-to-scale. Column 3 indicates the total factor energy efficiency based on constant return-to-scale which can be viewed as pure technical efficiency. Column 5 indicates the total factor energy efficiency based on variable return-to-scale. The last column shows the status of each one's return-to-scale. It is noticed that only five countries are efficient both in CRS and VRS. Quantity of efficient country in column 5 is more than that in column 3. Notice that the return-to-scale effect of top 14 countries in the table is in decreasing stage while most of the last 18 countries are in increasing stage.

It is interesting to analyze the situation of china. It can be observed from table 4 that China is in stage of decreasing return-to-scale effect and TFEE is ranked 30, still lower than all of the developed countries and most of the developing countries. This is mainly caused by lower technical efficiency shown in column 3. Therefore, there are at least 3 ways to enhance the total factor energy efficiency of China, including (1) improving the output of GDP, (2) re-arranging the allocation of energy inputs and non-resource inputs and (3) improving the technical efficiency of production.

No.	Country	TFEE-CRS	Rank	TFEE-VRS	Rank	RTS
1	United States	0.8654	8	1.0000	1	D
2	Japan	0.9177	6	1.0000	1	D
3	Germany	0.8179	10	1.0000	1	D
4	Britain	0.8016	11	1.0000	1	D
5	France	0.6395	17	1.0000	1	D
6	Italy	0.8892	7	1.0000	1	D
7	China	0.3139	32	0.8663	30	D
8	Canada	0.5787	18	0.8417	31	D
9	Mexico	0.7008	14	1.0000	1	D
10	Korea	0.3154	31	0.7827	37	D
11	India	0.3086	33	0.8897	28	D
12	Australia	0.6449	16	0.9020	26	D
13	Netherlands	0.7462	12	1.0000	1	D
14	Brazil	0.2581	37	0.8341	33	D
15	Russian Federation	0.0696	47	1.0000	1	C
16	Switzerland	1.0000	1	1.0000	1	C
17	Sweden	0.8394	9	1.0000	1	C
18	Austria	0.7431	13	0.8304	34	D
19	Turkey	0.3375	27	1.0000	1	C
20	Norway	1.0000	1	1.0000	1	C
21	Poland	0.5168	22	0.8130	35	D
22	Indonesia	0.1895	40	0.8941	27	D
23	Greece	0.5743	19	0.7196	42	D
24	Finland	0.6992	15	0.7779	38	I
25	South Africa	0.4727	25	0.7215	41	C

26	Ireland	1.0000	1	1.0000	1	C
27	Portugal	0.5362	21	0.6063	46	I
28	Thailand	0.1784	42	0.6815	44	D
29	Iran	1.0000	1	1.0000	1	C
30	Argentina	0.4820	23	1.0000	1	C
31	Malaysia	0.3039	34	0.8014	36	I
32	Czech Republic	0.3341	28	0.5315	48	I
33	Hungary	0.3335	29	0.6999	43	I
34	Egypt	0.5630	20	1.0000	1	C
35	Pakistan	0.2114	38	0.8803	29	I
36	Philippines	0.3321	30	1.0000	1	I
37	New Zealand	0.4625	26	0.9426	25	I
38	Columbia	0.2926	35	0.7719	39	I
39	Chile	0.2814	36	0.7570	40	I
40	Peru	0.4730	24	1.0000	1	C
41	Romania	0.1478	44	0.8352	32	I
42	Bangladesh	1.0000	1	1.0000	1	C
43	Ukraine	0.0442	48	0.5624	47	I
44	Slovakia	0.1883	41	0.6789	45	I
45	Kazakhstan	0.1065	45	1.0000	1	I
46	Bulgaria	0.1558	43	1.0000	1	I
47	Lithuania	0.2046	39	1.0000	1	I
48	Uzbekistan	0.0710	46	1.0000	1	I

*D, I and C indicate decreasing, increasing and constant return-to-scale respectively.

Table 4. TFEE of 48 countries

4. A dynamic analysis of energy efficiencies of 30 Chinese provinces during 2000-2003

This section aims to investigate the total factor energy efficiency of main areas in china using the time-series data from 2000 to 2003. These areas shown in table 5 include 12 provinces in the east area, 10 provinces in the central area and 8 provinces in the west area. Consisting of fast-developing regions like Beijing, Shanghai, Guangdong etc., the east area owns GDP output around half of the country. The central area contains inland provinces such as Shanxi, Jilin, Henan etc. This area has a large population and tremendous potential. Compared with the other areas, the west area is the least developed region in China, containing provinces of Sichuan, Guizhou, Yunnan etc. In our study, Tibet, which is also a province in the west area, is missing due to the unavailability of data. Similar as the analysis in the above section, GDP is the only output and non-resource inputs are capital stock and labor while energy inputs are represented as crud oil, coal and electric power. The data on energy input are collected from China Energy Statistical Year Book (2004). GDP and labor data are collected from the Statistical Year Book of China published by National Bureau of Statistics during 2000-2003. The data on capital stock comes from Jun et al. [23].

Areas	Num.	Provinces
East area	12	Beijing, Tianjin, Hebei, Liaoning, Shanghai, Jiangsu, Zhejiang, Fujian, Shandong, Guangdong, Guangxi, Hainan
Central area	10	Shanxi, Inner Mongolia, Jilin, Heilongjiang, Anhui, Jiangxi, Henan, Hubei, Hunan, Chongqing
West area	8	Sichuan, Guizhou, Yunnan, Shaanxi, Gansu, Qinghai, Ningxia, Xinjiang

Table 5. Chinese provinces in different areas

Curves in Figure 1 show the difference among the average TFEE scores of the provinces in the east, central and west areas using model (4). Obviously the east area is the most efficient and the west area is worst in any year. Meanwhile, it is shown that energy efficiencies for all areas are gradually improving. The detailed results are listed in Table 6. It can be easily observed from the table that most of efficient provinces are in the east area. TFEE scores of Liaoning, Shanghai, Jiangsu, Guangdong, Guangxi, Hainan, Fujian are all at a high level. Provinces in the central area are not as good as the provinces in the east area except Anhui which is adjacent to the east area. Another province in the central area, Shanxi, for specially, has very low TFEE scores during the four years and makes little progress. The situation in the west area is even worse other than Sichuan, Yunnan, Qinghai and Ningxia.

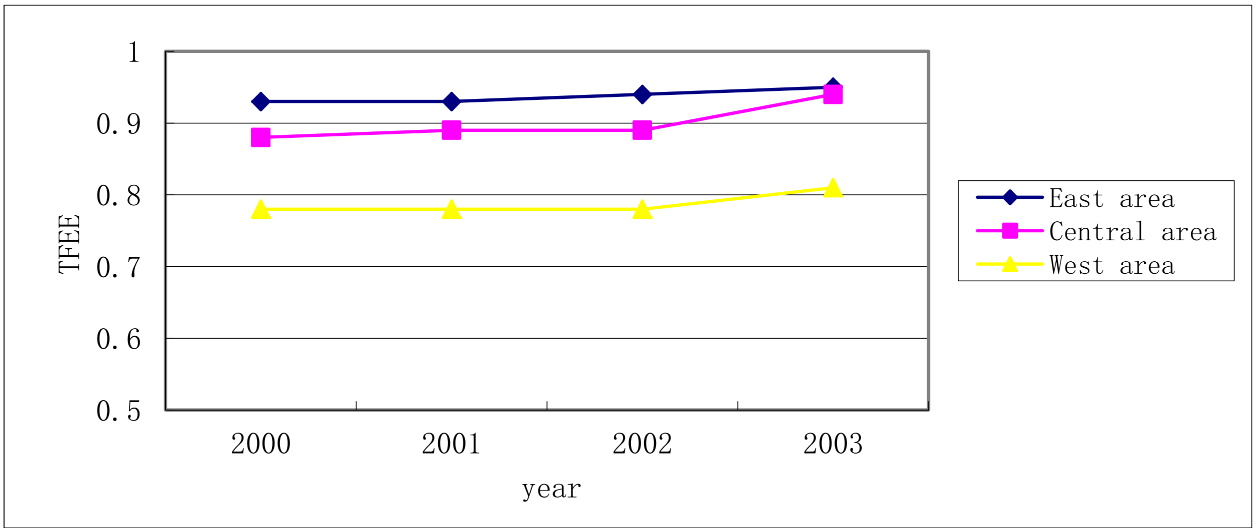

Figure 1. TFEE of 30 provinces during 2000-2003

Table 7 is used to clarify which part makes the energy efficiency get improvement. During 2000 to 2001, the average value of Malmquist production index (MPI) for all provinces is 1.13 which means the efficiency in 2001 is better than 2000. Catch-up effect (CE) and frontier-shift effect (FE) are two parameters to distinguish which part is functioned. The data on the last row show that the average value of CE is 1.00 and FE is 1.13. That is to say, the technical efficiency in 2001 is almost the same as that in 2000, while the production frontier gets improvement during the two years. Improvement is also achieved in next two years, but there is something different that both CE and FE are working.

In order to compare the trends of 3 areas, we make a summary in table 8 using the average data. It is clear that the central area has the greatest achievement and the west area is following. FE is always doing better than CE.

No.	Province	Area	2000	2001	2002	2003
1	Beijing	E	0.8644	0.9557	0.9634	1.0000
2	Tianjin	E	0.9911	1.0000	1.0000	1.0000
3	Hebei	E	0.7702	0.8028	0.7848	0.7663
4	Liaoning	E	1.0000	1.0000	1.0000	1.0000
5	Shanghai	E	1.0000	1.0000	1.0000	1.0000
6	Jiangsu	E	1.0000	1.0000	1.0000	1.0000
7	Zhejiang	E	0.9949	1.0000	1.0000	1.0000
8	Shandong	E	1.0000	0.8836	0.9994	1.0000
9	Guangdong	E	1.0000	1.0000	1.0000	1.0000
10	Guangxi	E	1.0000	1.0000	1.0000	0.9406
11	Hainan	E	1.0000	1.0000	1.0000	1.0000
12	Fujian	E	1.0000	1.0000	1.0000	1.0000
13	Shanxi	C	0.4510	0.4469	0.5150	0.5847
14	Inner M	C	0.6664	0.6929	0.7194	0.8298
15	Jilin	C	0.6657	0.6826	0.6890	0.7548
16	Heilongjiang	C	0.8323	0.7791	0.8795	0.9683
17	Anhui	C	1.0000	1.0000	1.0000	1.0000
18	Jiangxi	C	0.9508	0.9800	1.0000	1.0000
19	Henan	C	0.9075	0.9044	0.8967	1.0000
20	Hubei	C	1.0000	1.0000	0.9077	0.9541
21	Hunan	C	0.9284	0.9305	0.9138	0.9342
22	Chongqing	C	1.0000	1.0000	1.0000	1.0000
23	Sichuan	W	1.0000	1.0000	1.0000	1.0000
24	Guizhou	W	0.5258	0.5232	0.5203	0.6556
25	Yunnan	W	1.0000	1.0000	1.0000	1.0000
26	Shaanxi	W	0.5191	0.5307	0.5701	0.6067
27	Gansu	W	0.4206	0.4229	0.4153	0.4126
28	Qinghai	W	1.0000	1.0000	1.0000	1.0000
29	Ningxia	W	1.0000	1.0000	1.0000	1.0000
30	Xinjiang	W	0.7356	0.7431	0.7497	0.8371

*E, C and W indicate east area, central area and west area respectively.

Table 6. TFEE of 30 provinces during 2000-2003

No.	Province	2000-2001			2001-2002			2002-2003		
		CE	FE	MPI	CE	FE	MPI	CE	FE	MPI
1	Beijing	1.11	1.05	1.17	1.01	1.05	1.06	1.03	1.07	1.11
2	Tianjin	1.01	1.03	1.04	1.00	1.02	1.02	1.00	1.07	1.07
3	Hebei	1.04	1.16	1.20	0.98	1.13	1.11	0.98	1.11	1.09
4	Liaoning	1.00	1.04	1.04	1.00	1.00	1.00	1.00	1.09	1.09
5	Shanghai	1.00	1.16	1.16	1.00	1.14	1.14	1.00	1.19	1.19
6	Jiangsu	1.00	1.20	1.20	1.00	1.16	1.16	1.00	1.10	1.10
7	Zhejiang	1.00	1.08	1.08	1.00	1.09	1.09	1.00	1.13	1.13
8	Shandong	0.88	1.10	0.97	1.13	1.10	1.24	1.00	1.15	1.15
9	Guangdong	1.00	1.18	1.18	1.00	1.03	1.03	1.00	1.06	1.06
10	Guangxi	1.00	1.08	1.08	1.00	1.00	1.00	0.94	1.07	1.01
11	Hainan	1.00	0.23	0.23	1.00	1.01	1.01	1.00	0.72	0.72
12	Fujian	1.00	1.08	1.08	1.00	1.10	1.10	1.00	1.07	1.07
13	Shanxi	0.99	1.04	1.03	1.16	1.06	1.23	1.14	1.05	1.19
14	Inner M	1.04	1.04	1.08	1.04	1.12	1.16	1.15	1.04	1.20
15	Jilin	1.03	1.01	1.04	1.01	1.02	1.03	1.10	0.98	1.08
16	Heilongjiang	0.94	1.01	0.95	1.13	0.98	1.11	1.10	0.96	1.05
17	Anhui	1.00	1.06	1.06	1.00	1.03	1.03	1.00	1.07	1.07
18	Jiangxi	1.03	1.00	1.03	1.02	1.00	1.02	1.00	0.96	0.96
19	Henan	1.00	1.16	1.16	0.99	1.14	1.13	1.11	4.19	4.65
20	Hubei	1.00	1.02	1.02	0.91	1.03	0.94	1.05	0.99	1.04
21	Hunan	1.00	1.00	1.00	0.98	0.98	0.96	1.02	0.96	0.98
22	Chongqing	1.00	3.58	3.58	1.00	3.82	3.82	1.00	4.27	4.27
23	Sichuan	1.00	1.53	1.53	1.00	1.68	1.68	1.00	1.59	1.59
24	Guizhou	1.00	0.95	0.95	0.99	1.02	1.01	1.26	0.82	1.04
25	Yunnan	1.00	1.09	1.09	1.00	1.12	1.12	1.00	1.16	1.16
26	Shaanxi	1.02	1.00	1.02	1.07	0.99	1.06	1.06	0.96	1.02
27	Gansu	1.00	1.02	1.02	0.98	1.03	1.01	0.99	1.04	1.03
28	Qinghai	1.00	0.94	0.94	1.00	0.94	0.94	1.00	0.94	0.94
29	Ningxia	1.00	0.91	0.91	1.00	0.91	0.91	1.00	0.90	0.90
30	Xinjiang	1.01	1.01	1.02	1.01	1.01	1.02	1.12	0.97	1.09
	Average	1.00	1.13	1.13	1.01	1.16	1.17	1.04	1.26	1.30

Table 7. Changes of 30 provinces during 2000-2003

Areas	2000-2001			2001-2002			2002-2003		
	CE	FE	MPI	CE	FE	MPI	CE	FE	MPI
East area	1.00	1.03	1.04	1.02	1.07	1.09	1.01	1.07	1.08
Central area	1.00	1.32	1.32	1.01	1.35	1.36	1.06	1.71	1.81
West area	1.00	1.06	1.06	1.01	1.09	1.09	1.05	1.05	1.10

Table 8. Average data of areas during 2000-2003

It is interesting to investigate the individual province. Here are some examples. First, we make a comparison between Shanghai and Hainan both of which are efficient during the periods. However, detailed data indicate that Shanghai keeps making frontier forward gradually while Hainan are opposite except year 2002. This could be explained by that the location of Hainan on the frontier is on the edge. Second, take Beijing for example. Beijing is non-efficient from 2000 to 2002 and finally becomes efficient at 2003 by making efforts on improving technical efficiency and putting frontier forward. Third, energy efficiency of Shandong province suffers a decline and is back to the normal level later. MPI during first period is decreasing mainly caused by declining CE. In the next two years, some parameters get recovery which makes MPI increasing.

5. Conclusion

This chapter reviews the development process of the evaluation technique of energy efficiency and focuses on introducing the concept of energy intensity. However, missing the structure of energy consumption causes the energy efficiency estimated inaccurately. Thus, the current chapter introduces a weighed energy efficiency model based on DEA to fix it. Energy cannot produce production without non-energy inputs such as labor and capital. That's why we extend the method to the total factor energy efficiency model. Energy efficiency of China and other 47 countries in 2003 are employed to illustrate the models. Results show that unbalance of energy efficiency exists. For china, specially, it needs to adjust energy consumption structure as its poor energy efficiency and improve GDP since its total factor energy efficiency is at a lower level than some developed countries.

As a key part, the chapter adopts Malmquist production index technique to analyze the dynamic change in energy efficiency of Chinese provinces which can further explore the reason for the variation of energy efficiency deeply. The chapter uses the proposed models to investigate the changes in energy efficiency of provinces in china during the period of 2000 to 2003. We find that the east area has better energy efficiency than the central and west area but lower improving rapid. In addition, it is interesting to find that energy efficiency of most provinces improves due to the extending frontier. Although our work mainly focuses on estimating energy efficiency at the macro-level, it can provide guidance to managers and manufacturers at the micro level.

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Acknowledgement

We would like to thank the financial support by Program for New Century Excellent Talents in University, Ministry of Education of China and National Natural Science Foundation of China (Grant No. 70801056, 71121061, 71090401/71090400 and 71110107024).

6. References

[1] Ang, B., Monitoring changes in economy-wide energy efficiency: From energy-GDP ratio to composite efficiency index. Energy Policy, 2006. 34(5): p. 574-582.

[2] Ang, B., A statistical analysis of energy coefficients. Energy economics, 1991. 13(2): p. 93-110.

[3] Howarth, R.B., et al., Manufacturing energy use in eight OECD countries: Decomposing the impacts of changes in output, industry structure and energy intensity. Energy economics, 1991. 13(2): p. 135-142.

[4] A Greening, L., D.L. Greene, and C. Difiglio, Energy efficiency and consumption—the rebound effect—a survey. Energy Policy, 2000. 28(6): p. 389-401.

[5] Xu Xiping, liang Liang. Energy Efficiency and Productivity of China: Compared with other Countries. ICCS 2007, Part III, LNCS 4489, pp.988-991, 2007, Beijing, China.

[6] Charnes, A., W.W. Cooper, and E. Rhodes, Measuring the efficiency of decision making units. European Journal of Operational Research, 1978. 2(6): p. 429-444.

[7] Zhou, P., B.W. Ang, and K.L. Poh, A survey of data envelopment analysis in energy and environmental studies. European Journal of Operational Research, 2008. 189(1): p. 1-18.

[8] Mohammadi, A., et al., Energy efficiency improvement and input cost saving in kiwifruit production using Data Envelopment Analysis approach. Renewable Energy, 2011. 36(9): p. 2573-2579.

[9] Rao, X., et al., Energy efficiency and energy saving potential in China: An analysis based on slacks-based measure model. Computers & Industrial Engineering, 2011(0).

[10] Bian, Y. and F. Yang, Resource and environment efficiency analysis of provinces in China: A DEA approach based on Shannon's entropy. Energy Policy, 2010. 38(4): p. 1909-1917.

[11] Boyd, G.A. and J.X. Pang, Estimating the linkage between energy efficiency and productivity. Energy Policy, 2000. 28(5): p. 289-296.

[12] Hu, J.L. and S.C. Wang, Total-factor energy efficiency of regions in China. Energy Policy, 2006. 34(17): p. 3206-3217.

[13] Honma, S. and J.L. Hu, Total-factor energy efficiency of regions in Japan. Energy Policy, 2008. 36(2): p. 821-833.

[14] Honma, S. and J.L. Hu, Total-factor energy productivity growth of regions in Japan. Energy Policy, 2009. 37(10): p. 3941-3950.

[15] Odeck, J., Assessing the relative efficiency and productivity growth of vehicle inspection services: An application of DEA and Malmquist indices. European Journal of Operational Research, 2000. 126(3): p. 501-514.

[16] Tone, K., Malmquist productivity index. Handbook on data envelopment analysis, 2004: p. 203-227.

[17] Halkos, G.E. and N.G. Tzeremes, Exploring the existence of Kuznets curve in countries' environmental efficiency using DEA window analysis. Ecological Economics, 2009. 68(7): p. 2168-2176.

[18] Zhang, X.-P., et al., Total-factor energy efficiency in developing countries. Energy Policy, 2011. 39(2): p. 644-650.

[19] Banker, R.D., A. Charnes, and W.W. Cooper, Some models for estimating technical and scale inefficiencies in data envelopment analysis. Management science, 1984: p. 1078-1092.

[20] Cooper, W.W., L.M. Seiford, and J. Zhu, Handbook on data envelopment analysis. 2004, Springer.

[21] Färe, R., S. Grosskopf, and C.A.K. Lovell, The measurement of efficiency of production. Vol. 6. 1985: Springer.

[22] Boussemart, J.P., et al., Luenberger and Malmquist productivity indices: theoretical comparisons and empirical illustration. Bulletin of Economic Research, 2003. 55(4): p. 391-405.

[23] Jun, Z., W. Guiying, and Z. Jipeng, The Estimation of China's provincial capital stock: 1952—2000. Economic Research Journal, 2004. 10: p. 35-44.