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Research Article

Measuring the Productivity of Energy Consumption of Major Industries in China: A DEA-Based Method

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Data envelopment analysis can be applied to measure the productivity of multiple input and output decision-making units. In addition, the data envelopment analysis-based Malmquist productivity index can be used as a tool for measuring the productivity change during different time periods. In this paper, we use an input-oriented model to measure the energy consumption productivity change from 1999 to 2008 of fourteen industry sectors in China as decision-making units. The results show that there are only four sectors that experienced effective energy consumption throughout the whole reference period. It also shows that these sectors always lie on the efficiency frontier of energy consumption as benchmarks. The other ten sectors experienced inefficiency in some two-year time periods and the productivity changes were not steady. The data envelopment analysis-based Malmquist productivity index provides a good way to measure the energy consumption and can give China's policy makers the information to promote their strategy of sustainable development.

1. Introduction

In the nearly three decades since the implementation of the reform and opening-up policy in China, the annual average growth of gross domestic product (GDP) has been about 9.5%, and in the first decade of the 21st century this number has risen to 10%. Even in 2009, under the recession in the global economy, GDP still achieved 33.5353 trillion Yuan, with a growth of 8.7% (China Statistical Yearbook, 2009). In 2010, China's GDP has achieved 39.7983 trillion Yuan, a growth of 10.3%. After 30 years of sustained and rapid economic growth, China has created an economic miracle and replaced Japan as the second largest economy. On the other hand, China's development has many drawbacks, especially the conflict between people and the environment, such as the contamination of groundwater, carbon emissions, and high energy consumption [1]. Consequently, in recent decades, there has been increasing concern about how to achieve sustainable economic growth with lower energy consumption, and it has become the main problem of development in China [2].

In the 11th 5-year-plan time period, China drafted a strategy of sustainable development. To measure the productivity of economic growth comprehensively, the energy consumption per 10,000 Yuan of GDP is used to monitor the situation in different industries. In 2009 and 2010, energy consumption declined by 2.2% and 4.01%, respectively, per 10,000 Yuan GDP (China Statistical Yearbook, 2009, 2010). Considering the rising trend of China's economic development, the consumption of electricity, coal, crude oil, and natural gas is likely to increase continuously. Yet, this kind of statistical data only describes the trend of energy consumption. It is therefore worthwhile to develop a more profound measure of the factors affecting production efficiency under certain output conditions to act as the basis for policy making.

Productivity could be the ratio of GDP to the total input of factors at the macrolevel [3]. Recently, total factor productivity (TFP), which is defined as an index of all the output to all the input, has been usually used to measure production efficiency [4, 5]. Compared to other methods, TFP measures the contribution of technology progress and economies of scale to economic growth without the effect of land, capital, labour, and other traditional elements [6].

Malmquist productivity indices (MPIs), which are based on nonparametric distance functions, are often used to estimate the TFP changes [7]. Further, data envelopment analysis (DEA) can be employed to evaluate the distance functions [8]. DEA is a nonparametric, linear, programming method to measure the productivity of comparable multiple-input and multiple-output decision-making units (DMUs) [9]. Using DEA does not require *a priori* assumptions on the underlying functional form and information on prices [9]. Because of the incorporation of value judgment into the DEA method, decision-makers' preferences can be included in the analytical process [9].

Because of the features above, DEA has been widely used for the measuring of technology innovation [10], productivity improvement [11], and optimal allocation of resources [12, 13]. Färe et al. [14] develop a DEA-based Malmquist productivity index of productivity change by combining the idea of efficiency measuring from Farrell [15] and productivity measuring from Caves et al. [16] and then decompose the Malmquist productivity index into an index describing changes in technology and efficiency. As a result, using the DEA-based MPI to estimate the TFP changes is superior and suitable for measuring the productivity of energy consumption in China. Therefore, the objective of this research is to measure the MPIs of major industries in China by using the DEA approach, to analyse the TFP, and to provide recommendations for government to increase energy consumption efficiency.

DEA-based Malmquist productivity indices (MPIs) have been widely used in a variety of industries for productivity measuring. Some studied the financial industry by applying DEA-based MPI to measure bank's performance for technique efficiency [17–19]. Some studied the social service industry to measure the efficiency and productivity growth [20, 21]. Most of the studies fell into environmental or energy efficiency for different manufacturing sectors. For example, Hjalmarsson and Veiderpass [22] examined productivity growth in electricity retail distribution in Sweden over 17 years by using a DEA-based Malmquist index. Boyd and Pang [23] examined the energy efficiency of two segments of the glass industry by using DEA methods. Kulshreshtha and Parikh [24] studied the efficiency and productivity of coal mining in the Indian coal sector using detailed input and output data for underground and opencast coal mining for the period between 1985 and 1997. The nonparametric approach of data envelopment analysis, DEA, has been adopted for the performance analysis of different coal mining regions. Zaim [25] proposed a new definition of pollution intensity—the pollution per unit of manufacturing output—and used MPI to measure the productivity of US manufacturing sectors between 1974 and 1986. Önüt and Soner [26] studied the efficiency of energy use by SMEs (small medium size enterprises) in Turkey's manufacturing sector by using DEA. Chien and Hu [27] analysed the effects of renewable energy on the technical efficiency of 45 economies during the period 2001-2002 through data envelopment analysis (DEA). Zhou and Ang [28] applied DEA methods to measure the energy efficiency performances of 21 OECD countries. Chen and Ali [29] used a DEA Malmquist index to measure the productivity of the computer industry; the approach was illustrated with a set of Fortune Global 500 Computer and Office Equipment companies from 1991 to 1997. However, most studies related to energy consumption are at country level or only for one or a few manufacturing industries.

Only a few studied productivity for manufacturing industry in China. For instance, Chen [30] used the nonradial Malmquist productivity index to measure the productivity change of three major Chinese industries between 1966 and 1985. Xue et al. [31] measured the productivity of the construction industry in China from 1997 to 2003 by using a DEA-based MPI. Fang et al. [32] compared the relative technical efficiency performance of listed coal mining companies in China and the US advanced DEA linear programming. But no study has compared the productivity for China's energy consumption for 14 different manufacturing sectors. However, all studies that applied DEA-based MPI to any industry used time series data. The technique efficiency and production growth are the two key concerns when using DEA-based MPI to analyze productivity.

Therefore, this paper empirically contributes to present productivity research. Through the calculation for fourteen different manufacturing sectors' technical efficiency change and empirical production frontier shift values by applying linear programming techniques to DEA model, it concludes that manufacture of plastics, manufacture of general purpose machinery, manufacture of transportation equipment, and manufacture of construction are the only energy consumption efficiency sectors in China. The rest of this paper is organized as follows. The next section introduces the input-oriented Malmquist productivity index. Its application to China's major industry from 1997–2008 is then presented and discussed. Discussions, implications, and conclusions are given in the last section.

2. DEA-Based Malmquist Productivity Index

We have seen many studies using DEA-based MPI to calculate the performance of different industries. Following the spirit of MPI, we use it for measuring the productivity of energy consumption.

The Malmquist productivity index (MPIs) is based on the distance function and provides an approach to the analysis of multi-input and multioutput systems without any assumption of the production behaviour. Shepherd (1970) defined the distance function and it has been widely used. Note that the distance function can be defined as inputbased and outputbased. In this paper, we focus on the input-based distance function to describe the MPIs for measuring the energy consumption performance of different industry sectors in China and the distance to the empirical production frontier (EPF) for the inefficient DMUs.

Suppose x and y are the input and output vectors, respectively. $S^t(y)$ is the empirical production frontier. θ is the ratio of input reduction for reaching the EPF. The distance function can be defined as follows:

$$D^t\left(x^t, y^t\right) = \max\left\{\theta \mid \frac{x^t}{\theta} \in S^t\left(y\right)\right\}. \quad (1)$$

The MPIs in time period t can be defined as

$$\mathrm{MPI} = \frac{D^t\left(x^{t+1}, y^{t+1}\right)}{D^t\left(x^t, y^t\right)}, \quad (2)$$

where $D^t(x^t, y^t)$ is the distance function for measuring the distance from the position in the input and output space of time period t to the EPF at time t. $D^t(x^{t+1}, y^{t+1})$ is the distance function for measuring the distance from the position at time period $t+1$ to the EPF at time t.

The MIPs in time period $t+1$ can be defined as

$$\mathrm{MPI} = \frac{D^{t+1}\left(x^{t+1}, y^{t+1}\right)}{D^{t+1}\left(x^t, y^t\right)}, \quad (3)$$

where $D^{t+1}(x^{t+1}, y^{t+1})$ is the distance function for measuring the distance from the position in the input and output space at time period $t+1$ to the EPF at time $t+1$. $D^{t+1}(x^t, y^t)$ is the distance function for measuring the distance from the position at time period t to the EPF at time $t+1$.

Farrell (1989) defined the Malmquist productivity index as

$$\mathrm{MPI}_0 = \left[\frac{D_0^t(x_0^t, y_0^t)}{D_0^t(x_0^{t+1}, y_0^{t+1})} \frac{D_0^{t+1}(x_0^t, y_0^t)}{D_0^{t+1}(x_0^{t+1}, y_0^{t+1})}\right]^{1/2}. \quad (4)$$

In this paper, the MPI can be used to measure the change of energy consumption of different industries in China between time periods t and $t+1$. If $\mathrm{MPI}_0 > 1$, then the energy consumption performance declines; if $\mathrm{MPI}_0 = 1$, then it remains unchanged, and improves if $\mathrm{MPI}_0 < 1$.

To find out the reasons for MPI change, follow Färe et al. [14] and decompose the MPI into two components. Here, we also use this approach to investigate efficiency change and technical change, namely:

$$\mathrm{MPI}_0 = \frac{D_0^t\left(x_0^t, y_0^t\right)}{D_0^{t+1}\left(x_0^{t+1}, y_0^{t+1}\right)}\left[\frac{D_0^{t+1}(x_0^{t+1}, y_0^{t+1})}{D_0^t(x_0^{t+1}, y_0^{t+1})} \frac{D_0^{t+1}(x_0^t, y_0^t)}{D_0^t(x_0^t, y_0^t)}\right]^{1/2}, \quad (5)$$

where the first component measures the magnitude of the technical efficiency change (TEC) between time periods t and $t+1$, namely:

$$\mathrm{TEC}_0 = \frac{D_0^t\left(x_0^t, y_0^t\right)}{D_0^{t+1}\left(x_0^{t+1}, y_0^{t+1}\right)}. \quad (6)$$

TEC measures the catch-up effect, which indicates the energy consumption performance change in the reference periods.

The second component measures the EPF shift (EPFS) between time period t and $t+1$, namely:

$$\mathrm{EPFS}_0 = \left[\frac{D_0^{t+1}(x_0^{t+1}, y_0^{t+1})}{D_0^t(x_0^{t+1}, y_0^{t+1})} \frac{D_0^{t+1}(x_0^t, y_0^t)}{D_0^t(x_0^t, y_0^t)}\right]^{1/2}. \quad (7)$$

EPFS measures the frontier-shift effect, which indicates the shift in production technology of one industry. If $\mathrm{EPFS}_0 < 1$, then it means a positive shift of EPF or technical progress. $\mathrm{EPFS}_0 > 1$ indicates a negative shift of EPF or technical regression. If $\mathrm{EPFS}_0 = 1$, then the EPF is unchanged.

According to the theories above, MPI can be formulated as follows:

$$\mathrm{MPI}_0 = \mathrm{TEC}_0 \cdot \mathrm{EPFS}_0. \quad (8)$$

The basic idea for calculating the MPI of a DMU is to estimate the distance to EPF. Here, we will employ DEA methods to estimate the distance function. The aim of using this approach is to calculate the energy consumption efficiency and the degree of input reduction for reaching the EPF. The following model can be used to measure the performance in a time period and the distance can also be calculated. Suppose we have n DMUs, each DMU_j ($j = 1, 2, 3, \ldots, n$) produces a vector of outputs by using a vector of inputs at each time period t, $t = 1, \ldots, T$. The DEA model at time period t can be expressed as follows:

model (1)

$$\begin{aligned} & D_0^t\left(x_0^t, y_0^t\right) = \min \theta_0, \\ & \text{s.t.} \quad \sum_{j=1}^{n} \lambda_j x_j^t \le \theta_0 x_0^t, \\ & \qquad \sum_{j=1}^{n} \lambda_j y_j^t \ge y_0^t, \\ & \lambda_j \ge 0, \quad j = 1, \ldots, n, \end{aligned} \quad (9)$$

where $x_0^t = (x_{10}^t, \ldots, x_{m0}^t)$ and $y_0^t = (y_{10}^t, \ldots, y_{s0}^t)$ are the input and output vectors of DMU_0 among others.

Note that the DEA models used in the Malmquist productivity index can either be inputoriented or output-oriented. In this paper, we use an inputoriented model which considers the possible radial reductions of inputs when the outputs are fixed at the current level, which can indicate the amount of energy consumption reduction when the value added is fixed. In model (1), θ_0^* ($\theta_0^* = D_0^t(x_0^t, y_0^t)$) is the efficiency of DMU_0 at time period t which determines the amount by which observed inputs can be proportionally reduced. In this paper, if DMU_0's energy consumption performance is efficient in time period t and the amount of energy it has used cannot be reduced with the given value added, then DMU_0 is on the empirical production frontier (EPF). If it is energy consumption performance is inefficient and can still produce the given value added after reducing the proper amount of energy, which means DMU_0 is operating below the EPF [30], then it can reach the EPF after input reduction.

Suppose we have a production function in time period t as well as period $t+1$; the Malmquist productivity index calculation requires two single period and two mixed period measures (Charnes et al. 1978). From the time period t to $t+1$, DMU_0's technical efficiency and the EPF may shift. We adopt the algorithm developed by Färe et al. [20] to calculate the Malmquist production index by considering energy consumption. It can be calculated via the following steps.

(i) Comparing to EPF at time t, by calculating in model (1).

(ii) Comparing to EPF at time $t+1$ by calculating via the following linear program model:
model (2)

$$\begin{aligned} D_0^{t+1}\left(x_0^{t+1}, y_0^{t+1}\right) &= \min \theta_0, \\ \text{s.t.} \quad \sum_{j=1}^{n} \lambda_j x_j^{t+1} &\le \theta_0 x_0^{t+1}, \\ \sum_{j=1}^{n} \lambda_j y_j^{t+1} &\ge y_0^{t+1}, \\ \lambda_j \ge 0, \quad j &= 1, \ldots, n. \end{aligned} \tag{10}$$

(iii) Comparing to EPF at time $t+1$, by calculating via the following linear program model:
model (3)

$$\begin{aligned} D_0^{t+1}\left(x_0^{t}, y_0^{t}\right) &= \min \theta_0, \\ \text{s.t.} \quad \sum_{j=1}^{n} \lambda_j x_j^{t+1} &\le \theta_0 x_0^{t}, \\ \sum_{j=1}^{n} \lambda_j y_j^{t+1} &\ge y_0^{t}, \\ \lambda_j \ge 0, \quad j &= 1, \ldots, n. \end{aligned} \tag{11}$$

(iv) Comparing to EPF at time t, by calculating via the following linear program model:
model (4)

$$\begin{aligned} D_0^{t}\left(x_0^{t+1}, y_0^{t+1}\right) &= \min \theta_0, \\ \text{s.t.} \quad \sum_{j=1}^{n} \lambda_j x_j^{t} &\le \theta_0 x_0^{t+1}, \\ \sum_{j=1}^{n} \lambda_j y_j^{t} &\ge y_0^{t+1}, \\ \lambda_j \ge 0, \quad j &= 1, \ldots, n. \end{aligned} \tag{12}$$

3. Empirical Study

3.1. Data and DMU Selection. To measure the energy consumption efficiency of Chinese industry, we select industries which can represent its development, based on factors such as the contribution to GDP, business receipts compared to other industries, the influence on the economy, and the energy consumption compared to other industries. In China, the economy is divided into three main sectors: primary industry, secondary industry, and tertiary industry. Secondary industry accounts for an annual output value of 45%–48% of GDP, which is the largest proportion compared to the other two sectors. Secondary industry in China consists of industry and construction, which account for 40% and 6% of GDP, respectively. In the industry sector, manufacturing accounts for 20% of GDP. Moreover, coal consumption in these two sectors accounts for about 95% of the total consumption and 75% of electricity consumption. It means that the energy consumption efficiency in these industries can heavily influence the development of the Chinese economy. Based on the selection criteria above, 14 DMUs were chosen from the manufacturing industry and the construction sectors which consume more than 1 million tons of coal, 10,000 million kWh electricity and account for more than 50,000 million Yuan of gross industrial output value for each sector.

These 14 DMUs are 14 different sectors. They are sectors of manufacture of textile, manufacture of paper and paper products, manufacture of raw chemical materials and chemical products, manufacture of chemical fibers, manufacture of rubber, manufacture of plastics, manufacture of non-metallic mineral products, smelting and pressing of ferrous metals, smelting and pressing of nonferrous metals, manufacture of metal products, manufacture of general purpose machinery, manufacture of special purpose machinery, manufacture of transport equipment, and construction.

Choosing appropriate inputs and outputs is significant to get no biased relative performance among DMUs [33, 34]. However, the greater number of inputs and outputs will increase the difficulty of data collection. Traditionally, the input and output variables are identified by using the knowledge of subject experts. It is always a balance between meeting objectives of performance measurement and the number of input and output factors [35] see [33–35].

For each of these 14 different sectors, two most important inputs (coal consumption and electricity consumption) were chosen to be the input measurement with the unit of 10,000 tons and 100 million kwh, respectively. The gross industry output value was chosen to be the output measurement with the unit of 100 million Yuan at current price. The data was collected from the Statistical Yearbooks of China from the year of 1999 to the year of 2008 published every year by the National Bureau of Statistics of China. The summary statistics of coal consumption, electricity consumption, and gross industrial output value are shown in Table 1.

3.2. Measuring Process and Results Analysis. Table 2 represents the technical efficiency of the 14 sectors from 1999 to 2008, which is the result of model (1).

Table 2 shows the energy consumption efficiency of the 14 sectors from 1999 to 2008. From the results, there are 4 sectors that experienced effective energy consumption in the reference period, which means the value of $D_0^t(x_0^t, y_0^t)$ is equal to 1. It also shows that these sectors always lie on the efficiency frontier of energy consumption as benchmarks. Construction is effective from 1999 to 2002. The manufacture of transport equipment sector is effective from 2003 to 2008. The manufacture of plastics sector is effective from 2000

Table 1: Summary statistics of coal consumption, electricity consumption, and gross industrial output value of 13 manufacturing sectors and construction sector from 1999 to 2008.

Sectors	Coal consumption (10,000 tons)		Electricity consumption (100 million kwh)		Gross industrial output value (100 million yuan)	
	Mean	Std.	Mean	Std.	Mean	Std.
Manufacture of textile	1814.01	504.44	688.68	326.11	10916.54	6025.63
Manufacture of paper and paper products	2493.06	860.92	339.66	100.01	3669.68	2212.16
Manufacture of raw chemical materials and chemical products	9905.02	2596.04	1833.19	675.213	14503.23	9915.68
Manufacture of chemical fibers	777.86	34.78	220.42	36.85	2171.02	1227.67
Manufacture of rubber	327.98	68.72	164.83	74.29	1953.15	1207.75
Manufacture of plastics	189.94	63.63	238.11	126.20	4306.01	2944.0
Manufacture of nonmetallic mineral products	14003.97	4676.51	1224.16	484.82	8869.47	5860.59
Smelting and pressing of ferrous metals	16307.16	5115.42	2127.23	1062.01	17171.75	14088.82
Smelting and pressing of nonferrous metals	1923.73	721.15	1339.26	710.47	8056.28	6923.11
Manufacture of metal products	257.26	43.77	417.08	208.43	6268.15	4287.46
Manufacture of general purpose machinery	362.36	51.80	286.78	127.49	9692.43	7419.03
Manufacture of special purpose machinery	403.44	90.16	151.42	63.19	5815.30	4163.19
Manufacture of transport equipment	728.33	61.60	303.43	97.17	14725.13	9694.02
Construction	568.36	29.94	219.94	76.30	9426.89	4411.974

to 2003. Moreover, the of manufacture of general purpose machinery sector is effective in the time period 2004 to 2008. None of the other 10 sectors was effective in the whole time period. Five sectors, namely, construction, manufacture of plastics, manufacture of metal products, manufacture of transport equipment, and manufacture of general purpose machinery were the top five performers in the first five years, but manufacture of plastics is replaced by manufacture of special purpose machinery in the next five-year period. Another five sectors are always the bottom five performers over time, namely, smelting and pressing of ferrous metals, smelting and pressing of nonferrous, metals, manufacture of non-metallic mineral products, manufacture of raw chemical materials and chemical products, and the manufacture of chemical fibres. Similarly, the value of $D_0^{t+1}(x_0^t, y_0^t)$ and $D_0^t(x_0^{t+1}, y_0^{t+1})$ can be calculated from the models (3) and (4), respectively.

Using these two calculated values for formula (8), the Malmquist productivity index of China's major industry was computed as shown in Table 3. Because MPI can be decomposed into two components, TEC and EPFS (as shown in Tables 4 and 5), which mean technical change and frontier shift.

In order to analyse the productivity of energy consumption comprehensively, we use $(1/\mathrm{MPI}_0 - 1)$, $(1/\mathrm{TEC}_0 - 1)$, and $(1/\mathrm{EPFS}_0 - 1)$ to represent the change of MPI, TEC and EPFS, respectively. Tables 6(a), 6(b), and 6(c) show the value of $(1/\mathrm{MPI}_0 - 1)$, $(1/\mathrm{TEC}_0 - 1)$, and $(1/\mathrm{EPFS}_0 - 1)$.

Table 6(a) shows the value changes of MPI, three sectors maintain energy consumption productivity increasing throughout the whole time period, whose MPI value is less than 1. The other 11 sectors experienced productivity decline in some time periods. The sector productivity of manufacture of textiles declined 2.33%, 4.81%, and 0.79% in the time periods 1999-2000, 2004-2005, and 2005-2006, respectively. In time period 1999 to 2000, the TEC declined 0.54% and the shift of EPF was negative, decreasing by 1.81%. It is also noteworthy that in time periods 2004-2005 and 2005-2006, although this sector experienced a positive shift of EPF, which means the value of EPFS is less than 1, the TEC decreased 26.14% and 14.6%, respectively, which caused the decrease of MPI. Regarding the manufacture of plastics sector, its productivity decreased 2.35% in 2002-2003 and 57.83% in 2004-2005. The shift of EPF in 2002-2003 was negative, and the technical efficiency remained unchanged, which means the value of EPFS was greater than 1 and the value of TEC is equal to 1; therefore this time period shows a productivity decline. In 2004-2005, technical efficiency declined 59.15%, which is the main reason for the decline of the MPI, although it experienced a positive shift of EPF. For the manufacture of nonmetallic Mineral Products sector, the productivity declined 2.1% in 1999-2000, because the technical efficiency declined 0.3% and the EPF declined 1.81%. Its productivity went on to decline by 21.1% in 2004-2005, because of the sharp decline in technical efficiency, despite the positive shift of EPF. Regarding the smelting and

Table 2: Input-oriented CRS efficiency of sectors from 1999 to 2008.

Sector	$D_0^t(x_0^t, y_0^t)$									
	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
1	0.4075	0.4053	0.3774	0.4062	0.3572	0.3986	0.2944	0.2514	0.2563	0.2684
2	0.1894	0.1953	0.1754	0.1854	0.2042	0.2719	0.1953	0.1906	0.2234	0.2358
3	0.1281	0.1453	0.1300	0.1352	0.1429	0.1866	0.1470	0.1421	0.1484	0.1738
4	0.1691	0.1861	0.1273	0.1379	0.1758	0.2177	0.2140	0.2219	0.2290	0.2123
5	0.2798	0.3015	0.2845	0.3200	0.2853	0.3372	0.2504	0.2432	0.2333	0.2264
6	0.9262	1.0000	1.0000	1.0000	1.0000	0.7719	0.3153	0.7288	0.6715	0.5600
7	0.1414	0.1410	0.1240	0.1315	0.1381	0.2025	0.1240	0.1186	0.1290	0.1510
8	0.1122	0.1231	0.1198	0.0874	0.1530	0.2064	0.1611	0.1417	0.1416	0.1712
9	0.1331	0.1510	0.1428	0.2257	0.1307	0.1292	0.1392	0.1631	0.1535	0.1386
10	0.7447	0.8367	0.8155	0.6596	0.8392	0.7821	0.7701	0.8329	0.8043	0.7755
11	0.5697	0.7935	0.8044	0.8450	0.9325	1.0000	1.0000	1.0000	1.0000	1.0000
12	0.6757	0.6862	0.6883	0.8329	0.8044	0.9408	0.6367	0.6504	0.7111	0.8167
13	0.7510	0.7967	0.8340	0.9741	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
14	1.0000	1.0000	1.0000	1.0000	0.9944	0.9629	0.8270	0.7402	0.7211	0.7528

1: manufacture of textile; 2: manufacture of paper and paper products; 3: manufacture of raw chemical materials and chemical products; 4: manufacture of chemical fibers; 5: manufacture of rubber; 6: manufacture of plastics; 7: manufacture of nonmetallic mineral products; 8: smelting and pressing of ferrous metals; 9: smelting and pressing of nonferrous metals; 10: manufacture of metal products; 11: manufacture of general purpose machinery; 12: manufacture of special purpose machinery; 13: manufacture of transport equipment; 14: construction.

Table 3: MPI of the 14 DMUs.

Sectors	MPI								
	99-00	00-01	01-02	02-03	03-04	04-05	05-06	06-07	07-08
1	1.0239	0.9650	0.8922	0.9679	0.8751	1.0506	1.0080	0.9020	0.7933
2	0.9878	0.9708	0.9827	0.9011	0.7335	1.0803	0.9089	0.7872	0.8123
3	0.8979	0.9743	0.9989	0.9393	0.7475	0.9852	0.9176	0.8836	0.6816
4	0.9254	1.2740	0.9347	0.7786	0.7886	0.7894	0.8553	0.8944	0.9028
5	0.8910	0.9794	0.8213	0.8881	0.7928	1.1489	0.8406	0.8405	0.7647
6	0.7064	0.9174	0.7380	1.0241	0.9368	2.3711	0.3478	0.7832	0.8232
7	1.0215	0.9908	0.9799	0.9447	0.6664	1.2674	0.9272	0.8481	0.6599
8	0.9286	0.8957	1.4235	0.5672	0.7239	0.9940	1.0084	0.9230	0.6153
9	0.7442	0.9804	0.5588	1.4920	0.7395	0.8887	0.7016	0.8535	0.7154
10	0.6779	0.9382	0.9114	0.8111	0.8073	0.9837	0.7433	0.7473	0.7595
11	0.6562	0.9131	0.8516	0.7836	0.6141	1.0193	0.8201	0.7592	0.7328
12	0.9733	0.9194	0.7803	0.9089	0.8349	1.1467	0.8452	0.8295	0.6586
13	0.9293	0.8813	0.8056	0.7872	0.9557	0.7978	0.8457	0.8643	0.6992
14	0.9900	0.8964	0.9989	0.9624	1.0085	0.9035	0.9494	0.9007	0.6967

1: manufacture of textile; 2: manufacture of paper and paper products; 3: manufacture of raw chemical materials and chemical products; 4: manufacture of chemical fibers; 5: manufacture of rubber; 6: manufacture of plastics; 7: manufacture of nonmetallic mineral products; 8: smelting and pressing of ferrous metals; 9: smelting and pressing of nonferrous metals; 10: manufacture of metal products; 11: manufacture of general purpose machinery; 12: manufacture of special purpose machinery; 13: manufacture of transport equipment; 14: construction.

pressing of ferrous metals sector, there are two time periods that experienced productivity decline, namely, 2001-2002 and 2005-2006. In the time period 2001-2002, the productivity declined 29.75%, which was caused by the decline of TEC (27%) and EPFS (3.77%). In the time period 2005-2006, the productivity declined 0.84% caused by the decline of TEC (12.06%), although it had a positive shift of EPF.

In the 11 sectors where energy consumption productivity has declined, there are 7 sectors whose productivity always increases, except for one two-year time period. Manufacture of chemical fibres experienced a productivity decline in 2000-2001 (21.5%), which was caused by the sharp decline of the EPC (31.58%) although its EPF experiences a positive shift. For the smelting and pressing of nonferrous metals, the values of MPI were less than 1 in the reported time period, except for time period 2002-2003 (1.4920), which indicates a productivity increase from 1999 to 2002 and 2003 to 2008. Construction is another sector in which productivity has declined for only one year: by 0.84% in time period 2003 to 2004. The other 4 sectors manufacture of paper and paper

Table 4: Value of TEC.

Sectors	TEC								
	99-00	00-01	01-02	02-03	03-04	04-05	05-06	06-07	07-08
1	1.0054	1.0739	0.9290	1.1372	0.8961	1.3539	1.1710	0.9809	1.1958
2	0.9700	1.1137	0.9457	0.9081	0.7511	1.3922	1.0249	0.8531	1.2281
3	0.8817	1.1177	0.9612	0.9466	0.7655	1.2696	1.0347	0.9576	1.0304
4	0.9087	1.4615	0.9229	0.7846	0.8075	1.0173	0.9645	0.9692	1.3649
5	0.9280	1.0598	0.8888	1.1216	0.8463	1.3466	1.0297	1.0421	1.0518
6	0.9262	1.0000	1.0000	1.0000	1.2955	2.4480	0.4327	1.0853	1.0678
7	1.0030	1.1367	0.9430	0.9520	0.6824	1.6333	1.0456	0.9191	0.9977
8	0.9118	1.0276	1.3698	0.5716	0.7413	1.2810	1.1372	1.0003	0.9303
9	0.8820	1.0574	0.6325	1.7275	1.0114	0.9278	0.8538	1.0626	1.0018
10	0.8900	1.0261	1.2363	0.7860	1.0730	1.0156	0.9246	1.0356	0.9850
11	0.7179	0.9865	0.9520	0.9061	0.9325	1.0000	1.0000	1.0000	1.0000
12	0.9848	0.9969	0.8264	1.0354	0.8550	1.4778	0.9789	0.9146	0.9812
13	0.9427	0.9552	0.8563	0.9741	1.0000	1.0000	1.0000	1.0000	1.0000
14	1.0000	1.0000	1.0000	1.0057	1.0327	1.1643	1.1173	1.0265	1.0092

1: manufacture of textile; 2: manufacture of paper and paper products; 3: manufacture of raw chemical materials and chemical products; 4: manufacture of chemical fibers; 5: manufacture of rubber; 6: manufacture of plastics; 7: manufacture of nonmetallic mineral products; 8: smelting and pressing of ferrous metals; 9: smelting and pressing of nonferrous metals; 10: manufacture of metal products; 11: manufacture of general purpose machinery; 12: manufacture of special purpose machinery; 13: manufacture of transport equipment; 14: construction.

Table 5: Value of EPFS.

Sectors	EPFS								
	99-00	00-01	01-02	02-03	03-04	04-05	05-06	06-07	07-08
1	1.0184	0.8986	0.9603	0.8511	0.9766	0.7760	0.8608	0.9196	0.6634
2	1.0184	0.8717	1.0392	0.9923	0.9766	0.7760	0.8868	0.9228	0.6614
3	1.0184	0.8717	1.0392	0.9923	0.9766	0.7760	0.8868	0.9228	0.6614
4	1.0184	0.8717	1.0129	0.9923	0.9766	0.7760	0.8868	0.9228	0.6614
5	0.9602	0.9242	0.9241	0.7918	0.9368	0.8532	0.8163	0.8065	0.7271
6	0.7626	0.9174	0.7380	1.0241	0.7231	0.9686	0.8039	0.7216	0.7710
7	1.0184	0.8717	1.0392	0.9923	0.9766	0.7760	0.8868	0.9228	0.6614
8	1.0184	0.8717	1.0392	0.9923	0.9766	0.7760	0.8868	0.9228	0.6614
9	0.8438	0.9272	0.8835	0.8637	0.7312	0.9579	0.8218	0.8033	0.7141
10	0.7617	0.9143	0.7372	1.0320	0.7524	0.9686	0.8039	0.7216	0.7710
11	0.9140	0.9256	0.8945	0.8648	0.6585	1.0193	0.8201	0.7592	0.7328
12	0.9883	0.9222	0.9442	0.8778	0.9766	0.7760	0.8634	0.9069	0.6713
13	0.9858	0.9226	0.9408	0.8081	0.9557	0.7978	0.8457	0.8643	0.6992
14	0.9900	0.8964	0.9989	0.9569	0.9766	0.7760	0.8498	0.8775	0.6903

1: manufacture of textile; 2: manufacture of paper and paper products; 3: manufacture of raw chemical materials and chemical products; 4: manufacture of chemical fibers; 5: manufacture of rubber; 6: manufacture of plastics; 7: manufacture of nonmetallic mineral products; 8: smelting and pressing of ferrous metals; 9: smelting and pressing of nonferrous metals; 10: manufacture of metal products; 11: manufacture of general purpose machinery; 12: manufacture of special purpose machinery; 13: manufacture of transport equipment; 14: construction.

products, rubber, general purpose machinery, and special purpose machinery experienced productivity declines from 2004 to 2005, by 7.43%, 12.96%, 1.9%, and 12.79%, respectively.

The remaining three sectors have always increased productivity in each time period. For the manufacture of raw chemical materials and chemical products sector, its productivity increased 11.38%, 2.64%, 0.11%, 6.46%, 33.78%, 1.5%, 8.98%, 13.17%, and 46.72% in the corresponding time period, respectively. The improvement of productivity in 2007-2008 is the highest, reaching 46.72%, caused by the positive shift of EPF, whose improvement reached 51.19%, although it experienced a decline of TEC (2.95%). Regarding the sector of Manufacture of Metal Products, its productivity increased 47.52%, 6.59%, 9.72%, 23.28%, 23.87%, 1.65%, 34.54%, 33.82%, and 31.67%, respectively in the corresponding time period. The improvement in productivity in 1999-2000 is the highest and was caused by the increase of technical efficiency and a positive shift of EPF. For the manufacture of transport equipment sector, it also maintained increased productivity throughout the reported time period. In 2007-2008, its productivity improvement was the highest, reaching 43.02%. The result was caused by the positive shift of EPF, with the

Table 6: (a) Changes of MPI in each time period (unit: %). (b) Changes of TEC in each time period (unit: %). (c) Changes of EPFS in each time period (unit: %).

(a)

Sectors	1/MPI-1								
	99-00	00-01	01-02	02-03	03-04	04-05	05-06	06-07	07-08
1	−2.33	3.62	12.09	3.32	14.27	−4.81	−0.79	10.87	26.05
2	1.23	3.01	1.76	10.98	36.34	−7.43	10.03	27.04	23.10
3	11.38	2.64	0.11	6.46	33.78	1.50	8.98	13.17	46.72
4	8.06	−21.50	6.98	28.44	26.81	26.68	16.92	11.81	10.77
5	12.23	2.10	21.76	12.60	26.13	−12.96	18.97	18.98	30.77
6	41.57	9.00	35.50	−2.35	6.74	−57.83	187.52	27.68	21.47
7	−2.10	0.93	2.05	5.85	50.07	−21.10	7.85	17.91	51.54
8	7.69	11.64	−29.75	76.31	38.13	0.60	−0.84	8.34	62.52
9	34.37	2.00	78.94	−32.97	35.22	12.52	42.53	17.16	39.79
10	47.52	6.59	9.72	23.28	23.87	1.65	34.54	33.82	31.67
11	52.40	9.52	17.43	27.62	62.85	−1.90	21.94	31.72	36.45
12	2.75	8.77	28.15	10.02	19.77	−12.79	18.32	20.56	51.83
13	7.61	13.47	24.13	27.04	4.63	25.34	18.24	15.71	43.02
14	1.01	11.55	0.11	3.91	−0.84	10.68	5.33	11.03	43.53

1: manufacture of textile; 2: manufacture of paper and paper products; 3: manufacture of raw chemical materials and chemical products; 4: manufacture of chemical fibers; 5: manufacture of rubber; 6: manufacture of plastics; 7: manufacture of nonmetallic mineral products; 8: smelting and pressing of ferrous metals; 9: smelting and pressing of nonferrous metals; 10: manufacture of metal products; 11: manufacture of general purpose machinery; 12: manufacture of special purpose machinery; 13: manufacture of transport equipment; 14: construction.

(b)

Sectors	1/TEC-1								
	99-00	00-01	01-02	02-03	03-04	04-05	05-06	06-07	07-08
1	−0.54	−6.88	7.64	−12.06	11.59	−26.14	−14.60	1.95	−16.37
2	3.09	−10.21	5.74	10.12	33.14	−28.17	−2.43	17.22	−18.57
3	13.42	−10.53	4.04	5.64	30.63	−21.24	−3.35	4.43	−2.95
4	10.05	−31.58	8.35	27.45	23.84	−1.70	3.68	3.18	−26.73
5	7.76	−5.64	12.51	−10.84	18.16	−25.74	−2.88	−4.04	−4.92
6	7.97	0.00	0.00	0.00	−22.81	−59.15	131.11	−7.86	−6.35
7	−0.30	−12.03	6.04	5.04	46.54	−38.77	−4.36	8.80	0.23
8	9.67	−2.69	−27.00	74.95	34.90	−21.94	−12.06	−0.03	7.49
9	13.38	−5.43	58.10	−42.11	−1.13	7.78	17.12	−5.89	−0.18
10	12.36	−2.54	−19.11	27.23	−6.80	−1.54	8.15	−3.44	1.52
11	39.30	1.37	5.04	10.36	7.24	0.00	0.00	0.00	0.00
12	1.54	0.31	21.01	−3.42	16.96	−32.33	2.16	9.34	1.92
13	6.08	4.69	16.78	2.66	0.00	0.00	0.00	0.00	0.00
14	0.00	0.00	0.00	−0.57	−3.17	−14.11	−10.50	−2.58	−0.91

1: manufacture of textile; 2: manufacture of paper and paper products; 3: manufacture of raw chemical materials and chemical products; 4: manufacture of chemical fibers; 5: manufacture of rubber; 6: manufacture of plastics; 7: manufacture of nonmetallic mineral products; 8: smelting and pressing of ferrous metals; 9: smelting and pressing of nonferrous metals; 10: manufacture of metal products; 11: manufacture of general purpose machinery; 12: manufacture of special purpose machinery; 13: manufacture of transport equipment; 14: construction.

(c)

Sectors	1/EPFS-1								
	99-00	00-01	01-02	02-03	03-04	04-05	05-06	06-07	07-08
1	−1.81	11.28	4.13	17.50	2.40	28.87	16.17	8.74	50.74
2	−1.81	14.72	−3.77	0.78	2.40	28.87	12.76	8.37	51.19
3	−1.81	14.72	−3.77	0.78	2.40	28.87	12.76	8.37	51.19
4	−1.81	14.72	−1.27	0.78	2.40	28.87	12.76	8.37	51.19
5	4.14	8.20	8.21	26.29	6.75	17.21	22.50	23.99	37.53
6	31.13	9.00	35.50	−2.35	38.29	3.24	24.39	38.58	29.70

(c) Continued.

Sectors	1/EPFS-1								
	99-00	00-01	01-02	02-03	03-04	04-05	05-06	06-07	07-08
7	−1.81	14.72	−3.77	0.78	2.40	28.87	12.76	8.37	51.19
8	−1.81	14.72	−3.77	0.78	2.40	28.87	12.76	8.37	51.19
9	18.51	7.85	13.19	15.78	36.76	4.40	21.68	24.49	40.04
10	31.29	9.37	35.65	−3.10	32.91	3.24	24.39	38.58	29.70
11	9.41	8.04	11.79	15.63	51.86	−1.89	21.94	31.72	36.46
12	1.18	8.44	5.91	13.92	2.40	28.87	15.82	10.27	48.96
13	1.44	8.39	6.29	23.75	4.64	25.34	18.25	15.70	43.02
14	1.01	11.56	0.11	4.50	2.40	28.87	17.67	13.96	44.86

1: manufacture of textile; 2: manufacture of paper and paper products; 3: manufacture of raw chemical materials and chemical products; 4: manufacture of chemical fibers; 5: manufacture of rubber; 6: manufacture of plastics; 7: manufacture of nonmetallic mineral products; 8: smelting and pressing of ferrous metals; 9: smelting and pressing of nonferrous metals; 10: manufacture of metal products; 11: manufacture of general purpose machinery; 12: manufacture of special purpose machinery; 13: manufacture of transport equipment; 14: construction.

Table 7: Target for coal consumption from 1999 to 2008 (unit: 10,000 tons).

Sectors	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
1	457.58	500.56	503.51	514.64	460.51	643.67	588.91	548.81	511.71	535.27
2	134.12	154.60	163.64	178.21	150.58	219.32	193.40	180.42	172.78	197.01
3	497.48	558.86	571.72	618.14	551.09	774.70	760.31	732.75	732.02	849.58
4	98.52	120.84	92.74	96.04	86.34	110.13	121.22	114.87	112.56	99.34
5	78.82	74.32	74.56	80.56	76.55	113.08	90.93	87.86	86.68	103.76
6	163.99	134.25	136.44	104.16	134.94	174.08	70.51	164.65	151.20	174.94
7	342.91	358.98	365.14	390.15	337.00	549.57	427.35	420.02	425.01	524.02
8	413.90	460.08	517.63	390.15	596.55	955.95	997.86	910.30	920.62	1119.12
9	181.13	179.77	180.85	295.01	186.92	270.39	311.64	393.90	404.23	457.68
10	223.76	179.48	182.14	143.31	169.89	210.75	210.46	220.08	213.14	265.66
11	272.12	266.34	279.90	279.13	296.02	340.35	340.58	354.39	342.89	436.37
12	200.08	212.44	207.75	222.24	228.41	321.68	282.82	284.99	289.33	363.33
13	470.66	517.16	562.64	661.97	668.48	802.90	730.35	730.39	741.55	835.57
14	522.46	536.82	537.98	553.54	446.53	480.15	470.97	424.67	389.63	454.08

1: manufacture of textile; 2: manufacture of paper and paper products; 3: manufacture of raw chemical materials and chemical products; 4: manufacture of chemical fibers; 5: manufacture of rubber; 6: manufacture of plastics; 7: manufacture of nonmetallic mineral products; 8: smelting and pressing of ferrous metals; 9: smelting and pressing of nonferrous metals; 10: manufacture of metal products; 11: manufacture of general purpose machinery; 12: manufacture of special purpose machinery; 13: manufacture of transport equipment; 14: construction.

technical efficiency remaining unchanged since the value of TEC was equal to 1.

The above analysis shows that, of the top five effective sectors in the reported time period, the manufacture of transport equipment and metal products sectors experienced positive performance change in every time period. The energy consumption efficiency of the manufacture of general purpose machinery declined slightly in 2004-2005 (1.9%), and construction also declined slightly in 2001-2002 (0.11%). Manufacture of special purpose machinery declined only in 2004-2005 (12.79%). Figure 1 shows that five sectors experienced significant changes in their energy consumption performance in most two-year time periods from 1999 to 2008. Also, the productivity changes were not steady in these sectors, which changed greatly in the reference period.

Analyzing DEA efficiency is to investigate whether DMU is on the efficient frontier. Therefore, we can use the projection on the EPF to calculate the distance for an inefficient DMU to the EPF. Then, the direction for sector regulation and the amount of energy input reduction can be determined when the output the gross industrial output value is fixed at the current level. Moreover, we can predict the projection on the EPF, which can in fact provide solutions for the inefficient DMU. Thus, this can be the basis for policy makers to promote the development of these sectors. Tables 7 and 8 show the efficiency target for each sector.

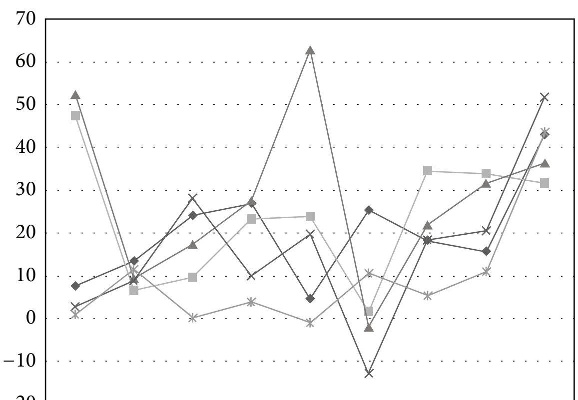
4. Discussions, Implications, and Conclusions

DEA can be applied for measuring multiple input and output DMUs' productivity. Also, the DEA-based Malmquist productivity index can be used as a tool for measuring the productivity change during different time periods. In this paper, we use an input-oriented model to measure the energy consumption productivity change from 1999 to 2008 of 14 industry sectors in China. Färe et al. [14] decompose MPI

Table 8: Target for electricity consumption from 1999 to 2008 (Unit: 100 million kwh).

Sectors	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
1	124.66	144.32	145.63	184.47	194.61	286.74	241.90	259.27	292.64	302.32
2	36.54	44.57	44.08	52.84	63.64	97.70	79.44	85.24	98.81	111.27
3	135.53	161.12	154.00	183.30	232.90	345.11	312.31	346.17	418.63	479.84
4	26.84	34.84	24.98	28.48	36.49	49.06	49.79	54.27	64.37	56.10
5	21.47	28.62	30.34	34.84	36.44	50.37	52.28	57.63	62.33	61.36
6	44.68	116.14	127.14	143.53	171.00	143.10	71.21	180.68	200.47	196.84
7	93.42	103.50	98.35	115.69	142.42	244.82	175.54	198.43	243.06	295.97
8	112.76	132.65	139.43	115.69	252.11	425.85	409.89	430.06	526.49	632.08
9	49.35	101.23	102.35	185.94	140.02	162.51	204.63	298.07	373.75	348.14
10	60.96	155.27	169.73	186.08	215.29	173.24	212.54	241.51	282.59	298.91
11	74.14	122.64	135.32	170.28	231.27	279.78	343.95	388.90	454.62	490.99
12	54.51	62.32	64.77	85.67	96.53	143.30	116.17	134.64	165.46	205.21
13	128.23	155.79	190.34	251.87	282.51	357.67	300.00	345.06	424.08	471.93
14	142.34	154.77	144.91	164.14	188.71	213.89	193.46	200.63	222.82	276.54

1: manufacture of textile; 2: manufacture of paper and paper products; 3: manufacture of raw chemical materials and chemical products; 4: manufacture of chemical fibers; 5: manufacture of rubber; 6: manufacture of plastics; 7: manufacture of nonmetallic mineral products; 8: smelting and pressing of ferrous metals; 9: smelting and pressing of nonferrous metals; 10: manufacture of metal products; 11: manufacture of general purpose machinery; 12: manufacture of special purpose machinery; 13: manufacture of transport equipment; 14: construction.



	99-00	00-01	01-02	02-03	03-04	04-05	05-06	06-07	07-08
Manufacture of transport equipment	7.61	13.47	24.13	27.04	4.63	25.34	18.24	15.71	43.02
Manufacture of metal products	47.52	6.59	9.72	23.28	23.87	1.65	34.54	33.82	31.67
Manufacture of general purpose machinery	52.4	9.52	17.43	27.62	62.85	−1.9	21.94	31.72	36.45
Manufacture of special purpose machinery	2.75	8.77	28.15	10.02	19.77	−12.79	18.32	20.56	51.83
Construction	1.01	11.55	0.11	3.91	−0.84	10.68	5.33	11.03	43.53

Figure 1: The changes of MPI in top five effective sectors (unit: %).

into two components: TEC and EPFS. As shown in this paper, TEC is used to measure the technical change, and EPFS shows the shift of the empirical production frontier. According to formula (8), TEC and EPFS reflect the value of MPI, so the changing of productivity will be determined by the technical change or the shift of frontier.

The results suggest that there are only four sectors, manufacture of plastics, panufacture of general purpose machinery, manufacture of transport equipment, and construction, that experienced effective energy consumption. It also shows that these sectors always lie on the efficiency frontier of energy consumption as benchmarks. Five sectors are always the bottom five performers over time, namely, smelting and pressing of ferrous metals, smelting and pressing of nonferrous metals, manufacture of nonmetallic mineral products, manufacture of raw chemical materials and chemical products and the manufacture of chemical fibres. The value changes of MPI indicates that three sectors, manufacture of raw chemical materials and chemical products, smelting and pressing of ferrous metals, and construction, maintain energy the increasing of consumption productivity throughout the whole time period. It also shows that the other eleven sectors where energy consumption productivity has declined. In addition, among these eleven sectors, seven sectors' productivity always increases, except for one two-year time period. But the other four sectors—manufacture of paper and paper products, rubber, general purpose machinery, and special purpose machinery—experienced productivity declines.

As a conclusion, three sectors including manufacture of raw chemical materials and chemical products sector, manufacture of transport equipment sector, and manufacture of metal products sector, have always increased productivity in each time period. Further, increasing productivity of the first two sectors was caused by the positive shift of empirical production frontier (EPF). However, increasing productivity of the last sector was caused by both the positive shift of EPF and the increase of technical efficiency (TEC). Overall, the top five effective sectors in the reported time period are manufacture of transport equipment, manufacture of metal products, manufacture of general purpose machinery, construction, and manufacture of special purpose machinery sectors.

To promote the productivity of energy consumption of major industry sectors in China, it is necessary for the Chinese government to make policies to strengthen energy management, especially in the sectors which need large amounts of energy input with low value added. In this paper, following the spirit of the DEA-based Malmquist productivity index, we calculate the distance for an inefficient DMU to the EPF. Then, the direction of sector promotion and the amount of energy consumption reduction can be determined. The target of energy consumption can be the basis for the government to make sustainable industrial policies. Alternatively, our DEA productivity analyses raise a question about how to establish energy saving policies. In our opinion, restructuring of industry, developing programs of technology innovation, and encouraging the reuse of input resources can be the solutions. However, this is beyond the scope of the current paper and should be left for further research.

This paper provides a way to measure the energy consumption performance of China's major industrial sectors, and the performance can be improved by reducing inputs to below the current output level. Note that in the radial DEA model there is always a DMU as the benchmark whose $D_0^t(x_0^t, y_0^t)$ is equal to 1. This is because the Malmquist productivity index is only based upon the radial DEA scores, ignoring nonzero input slacks in the input-oriented index [30]. Therefore, this cannot measure the energy consumption performance change comprehensively for every sector. Using a nonradial Malmquist productivity index can be the solution that can be incorporated with the preference over individual input improvement since it does not allow the existence of nonzero input slacks. This will be a direction for a future study.

Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

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References

[1] J. Liu and J. Diamond, "China's environment in a globalizing world," *Nature*, vol. 435, no. 7046, pp. 1179–1186, 2005.

[2] M. Asif and T. Muneer, "Energy supply, its demand and security issues for developed and emerging economies," *Renewable and Sustainable Energy Reviews*, vol. 11, no. 7, pp. 1388–1413, 2007.

[3] J. Felipe, "Total factor productivity growth in East Asia: a critical survey," *Journal of Development Studies*, vol. 35, no. 4, pp. 1–41, 1999.

[4] M. M. Fischer, T. Scherngell, and M. Reismann, "Knowledge spillovers and total factor productivity: evidence using a spatial panel data model," *Geographical Analysis*, vol. 41, no. 2, pp. 204–220, 2009.

[5] B. Kitcher, I. P. McCarthy, S. Turner, and K. Ridgway, "Understandinig the effects of outsourcing: unpacking the total factor productivity variable," *Production Planning & Control*, vol. 24, no. 4-5, pp. 308–317, 2013.

[6] J. Fagerberg, "Technology and international differences in growth rates," *Journal of Economic Literature*, vol. 32, no. 3, pp. 1147–1175, 1994.

[7] F. Sufian, "Total factor productivity change in non-bank financial institutions: evidence from Malaysia applying a malmquist productivity index (MPI)," *Applied Econometrics and International Development*, vol. 7, no. 1, pp. 177–186, 2007.

[8] S. E. Atkinson, C. Cornwell, and O. Honerkamp, "Measuring and decomposing productivity change: stochastic distance function estimation versus data envelopment analysis," *Journal of Business and Economic Statistics*, vol. 21, no. 2, pp. 284–294, 2003.

[9] W. D. Cook and L. M. Seiford, "Data envelopment analysis (DEA)—thirty years on," *European Journal of Operational Research*, vol. 192, no. 1, pp. 1–17, 2009.

[10] J. Sarkis and J. Weinrach, "Using data envelopment analysis to evaluate environmentally conscious waste treatment technology," *Journal of Cleaner Production*, vol. 9, no. 5, pp. 417–427, 2001.

[11] M. Bevilacqua and M. Braglia, "Environmental efficiency analysis for ENI oil refineries," *Journal of Cleaner Production*, vol. 10, no. 1, pp. 85–92, 2002.

[12] R. J. Kuo, Y. C. Wang, and F. C. Tien, "Integration of artificial neural network and MADA methods for green supplier selection," *Journal of Cleaner Production*, vol. 18, no. 12, pp. 1161–1170, 2010.

[13] H. Fukuyama, H. Masaki, K. Sekitani, and J. Shi, "Distance optimization approach to ratio-form efficiency measures in data envelopment analysis," *Journal of Productivity Analysis*, 2013.

[14] R. Färe, S. Grosskopf, B. Lindgren, and P. Roos, "Productivity changes in Swedish pharamacies 1980–1989: a non-parametric Malmquist approach," *Journal of Productivity Analysis*, vol. 3, no. 1-2, pp. 85–101, 1992.

[15] M. J. Farrell, “The measurement of productive efficiency,” *Journal of the Royal Statistical Society A*, vol. 120, no. 3, pp. 253–290, 1957.

[16] D. W. Caves, L. R. Christensen, and W. E. Diewert, “The economic theory of index numbers and the measurement of input, output, and productivity,” *Econometrica*, vol. 50, no. 6, pp. 1393–1414, 1982.

[17] P. L. Brockett, A. Charnes, W. W. Cooper, Z. M. Huang, and D. B. Sun, “Data transformations in DEA cone ratio envelopment approaches for monitoring bank performances,” *European Journal of Operational Research*, vol. 98, no. 2, pp. 250–268, 1997.

[18] K. Mukherjee, S. C. Ray, and S. M. Miller, “Productivity growth in large US commercial banks: the initial post-deregulation experience,” *Journal of Banking and Finance*, vol. 25, no. 5, pp. 913–939, 2001.

[19] Y. H. Chiu, Y. C. Chen, and X. J. Bai, “Efficiency and risk in Taiwan banking: SBM super-DEA estimation,” *Applied Economics*, vol. 43, no. 5, pp. 587–602, 2011.

[20] R. Färe, S. Grosskopf, and C. A. K. Lovell, *Production Frontiers*, University Press, Cambridge Cambridge, U.K, 1994.

[21] J. Odeck, “Assessing the relative efficiency and productivity growth of vehicle inspection services: an application of DEA and Malmquist indices,” *European Journal of Operational Research*, vol. 126, no. 3, pp. 501–514, 2000.

[22] L. Hjalmarsson and A. Veiderpass, “Productivity in Swedish electricity retail distribution,” *Scand Journal of Economics*, vol. 94, pp. 193–205, 1992.

[23] G. A. Boyd and J. X. Pang, “Estimating the linkage between energy efficiency and productivity,” *Energy Policy*, vol. 28, no. 5, pp. 289–296, 2000.

[24] M. Kulshreshtha and J. K. Parikh, “Study of efficiency and productivity growth in opencast and underground coal mining in India: a DEA analysis,” *Energy Economics*, vol. 24, no. 5, pp. 439–453, 2002.

[25] O. Zaim, “Measuring environmental performance of state manufacturing through changes in pollution intensities: a DEA framework,” *Ecological Economics*, vol. 48, no. 1, pp. 37–47, 2004.

[26] S. Önüt and S. Soner, “Analysis of energy use and efficiency in Turkish manufacturing sector SMEs,” *Energy Conversion and Management*, vol. 48, no. 2, pp. 384–394, 2007.

[27] T. Chien and J. L. Hu, “Renewable energy and macroeconomic efficiency of OECD and non-OECD economies,” *Energy Policy*, vol. 35, no. 7, pp. 3606–3615, 2007.

[28] P. Zhou and B. W. Ang, “Linear programming models for measuring economy-wide energy efficiency performance,” *Energy Policy*, vol. 36, no. 8, pp. 2901–2906, 2008.

[29] Y. Chen and A. I. Ali, “DEA Malmquist productivity measure: new insights with an application to computer industry,” *European Journal of Operational Research*, vol. 159, no. 1, pp. 239–249, 2004.

[30] Y. Chen, “A non-radial Malmquist productivity index with an illustrative application to Chinese major industries,” *International Journal of Production Economics*, vol. 83, no. 1, pp. 27–35, 2003.

[31] X. L. Xue, Q. P. Shen, Y. W. Wang, and J. F. Lu, “Measuring the productivity of the construction industry in China by using DEA-based malmquist productivity indices,” *Journal of Construction Engineering and Management*, vol. 134, no. 1, pp. 64–71, 2008.

[32] H. Fang, J. Wu, and C. Zeng, “Comparative study on efficiency performance of listed coal mining companies in China and the US,” *Energy Policy*, vol. 37, no. 12, pp. 5140–5148, 2009.

[33] L. Jenkins and M. Anderson, “A multivariate statistical approach to reducing the number of variables in data envelopment analysis,” *European Journal of Operational Research*, vol. 147, no. 1, pp. 51–61, 2003.

[34] B. Casu, D. Shaw, and E. Thanassoulis, “Using a group support system to aid input-output identification in DEA,” *Journal of the Operational Research Society*, vol. 56, no. 12, pp. 1363–1372, 2005.

[35] J. M. Wagner and D. G. Shimshak, “Stepwise selection of variables in data envelopment analysis: procedures and managerial perspectives,” *European Journal of Operational Research*, vol. 180, no. 1, pp. 57–67, 2007.