Analysis of Energy Efficiency Based on Malmquist Productivity index

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Abstract—Energy efficiency is the inverse of intensity, but it measures the specific output and efficiency of a process. It depends on changes in industrial processes, consumption practices and technology. After entering in the new millennium, energy efficiency and energy conservation have become an important part for a county to set energy policies. In this context, this paper aims to analyze total energy efficiency and industrial energy efficiency over the period 2000-2006 of Beijing. Using non-parametric methodologies, Malmquist productivity index (MPI) based on Data Envelopment Analysis (DEA), we decompose the productivity index into technical change and technical efficiency components. The results show that the average growth of total energy efficiency in Beijing from 2000 to 2006 is 6.4%, which benefits from technical progress, especially, from technical progress in the secondary industry.

Keywords—Energy efficiency; technical change; technical efficiency; Malmquist productivity index

I. INTRODUCTION

Energy efficiency is the inverse of intensity, but it measures the specific output and efficiency of a process. It depends on changes in industrial processes, consumption practices and technology. After entering in the new millennium, energy efficiency and energy conservation have become an important part for a county to set energy policy and responded to a range of challenges including perceptions of resource scarcity, high energy prices, security of energy supply and environmental protection [1].

After reform and opening up to the outside world, china has achieved a great advance in social and economic development. But, industrialization and economic development in China excessively depend on high investment and high energy consumption to realize high growth and achieve economies of scale in production, which brings serious effects on sustainable development and environment. Presently, people pay many attentions to increasing energy demand and gradually worsened environmental pollution, energy saving and greenhouse gas emissions reduction and energy problems have been raised to an unprecedentedly strategic level. From this angle, improvements in energy efficiency in China are seen as a key mechanism for reducing energy dependence and meeting sustainability and security of supply goals.

Till now, most of the current research in china has focused on the evaluation of energy efficiency and the determinant factors analysis. Although, different literatures give different definitions on energy efficiency, in general, energy efficiency refers to using less energy to produce the same amount of services or useful output. Starting from this definition, some early studies on energy efficiency is under single-factor productivity framework. The main disadvantage of this methodology is that it only measures the ratio of the single factor of energy and economic output and doesn’t consider other input factors’ effects. Therefore, nowadays, more and more researchers adopts total-factor productivity framework [2-4]. The results of reference [5] indicate that energy efficiency indicator based on the total-factor productivity framework can overcome the disadvantages of the indicator based on the single-factor productivity framework.

Since the outbreak of world oil crisis in 1973, the enthusiasm was further enhanced by the world-wide awareness and concern on energy and environmental issues. Energy researchers have expressed great enthusiasm in formulating and applying analytical/modeling techniques in energy studies [6]. A number of modeling techniques have as a result been developed and employed to address complex energy and environmental (E&E) issues. DEA is one kind of methods which have achieved compressive applications in energy field. Built upon the earlier work of Farrell (1957), Data Envelopment Analysis (DEA) is a relatively new “data oriented” approach for evaluating the performance of a set of comparable entities called Decision Making Units (DMUs) which convert multiple inputs into multiple outputs. So, DEA has become a popular method in measuring energy efficiency at the macro-economy level. Many researchers use this method to evaluate energy efficiency in China. Reference [7] measured Beijing’s energy efficiency based on data from 1996 to 2006 under DEA method. Reference [8] evaluated China’s industrial energy efficiency based on the data of 28 administrative regions from 2000-2006 by extended DEA model. Reference [4] established energy efficiency indicators considering technical change based on DEA and then calculate the energy efficiency of different provinces.

In the foregoing use of DEA is restricted to multilateral comparisons among different DMUs at the same point in time. However, in the case of energy sectors, there is generally a great interest in investigating their productivity change over time. The nonparametric Malmquist productivity index (MPI) is such a formal time-series analysis method for conducting performance comparisons of DMUs over time. MPI can be decomposed into technical change, technical efficiency change, pure efficiency change and scale efficiency change, which can
help researchers to know which factors drive energy efficiency to change and its magnitude.

The current paper tries to analyze energy efficiency of Beijing and its three industries from the technical change and efficiency change over the period from 2000 to 2006. The paper establishes energy efficiency indicators based on non-parametric DEA Malmquist productivity index. The remainder of this paper is as follows: Section 2 gives the brief description of Malmquist productivity index and detailed explanation of input indicators. In section 3, the Decomposed Malmquist indices are applied and the results presented. Concluding remarks are given in Section 4.

II. METHODOLOGY AND DATA DESCRIPTION

A. Malmquist productivity index

The Malmquist index was originally presented in the consumer theory context by Malmquist in 1953, which is interpreted as a ratio between two proportional scaling factors or distance functions. Caves, Christensen and Diewert developed Malmquist index in a general production function framework in 1982, and introduced two types of productivity, i.e. input-oriented MPI and out-oriented MPI. The Malmquist index has some advantages over other productivity indices. First, it does not require input prices or output prices, which makes it particularly useful in situations where prices are misrepresented or non-existent. Second, the Malmquist index does not require the profit maximization or cost minimization assumption. This makes it useful in situations where the behavior of producers is unknown or not achieved. Malmquist index has a very attractive characteristic that it can be decomposed into technical efficiency change and technical change, which makes it a popular method used in many fields. The value of its decomposition can provides insight into the sources of productivity change [9]. There are many methods developed to calculate distance functions and among them, DEA is the most popular method to calculate distance functions. The paper uses input-oriented MPI based on DEA under the hypothesis of constant returns to scale.

\[ x' = (x_1', x_2', ..., x_n') \geq 0 \]  
\[ x' \]  is the input of period \( t \)

\[ y' = (y_1', y_2', ..., y_m') \geq 0 \]  
\[ y' \]  is the output of period \( t \)

Assume that \( D_0^1(x^t, y^t) \) and \( D_0^{+1}(x^t, y^t) \) are the input-oriented efficiency measures of DMU \( 0 \) based on its inputs and outputs at period \( t \) for the reference technology at \( t \) and \( t+1 \). Further assume that \( D_0^1(x^{+1}, y^{+1}) \) and \( D_0^{+1}(x^{+1}, y^{+1}) \) are the input-oriented efficiency measures of DMU \( 0 \) based on its inputs and outputs at period \( t+1 \) for the reference technology at \( t \) and \( t+1 \). The input-oriented MPI can be defined as

\[
M_{PI}(x', y', x^{+1}, y^{+1}) = \left[ \frac{D_0^1(x^{+1}, y^{+1})}{D_0^1(x', y')} \times \frac{D_0^{+1}(x^{+1}, y^{+1})}{D_0^{+1}(x', y')} \right]^{1/2}
\]  

Equation (1) can be changed into

\[
\frac{D_0^1(x^{+1}, y^{+1})}{D_0^1(x', y')} \times \frac{D_0^{+1}(x^{+1}, y^{+1})}{D_0^{+1}(x', y')} = \left[ \frac{D_0^1(x^{+1}, y^{+1})}{D_0^1(x', y')} \right]^{1/2} \]  

The calculation of MPI can use the distance function of DEA. This paper uses software DEAP 2.1 to achieve results. The four distance functions \( D_0^1(x', y') \), \( D_0^{+1}(x^{+1}, y^{+1}) \), \( D_0^1(x^{+1}, y^{+1}) \) and \( D_0^{+1}(x', y') \) can be calculated as follows.

\[
D_0^1(x^{+1}, y^{+1})^{-1} = \max_{\theta, \lambda} \theta
\]

\[
\theta_{ij}^{+1} \leq \lambda' Y^t
\]

Such that

\[
\lambda' X^t \leq x^{+1}
\]

\[
\lambda \geq 0
\]

\[
D_0^{+1}(x^{+1}, y^{+1})^{-1} = \max_{\theta, \lambda} \theta
\]

\[
\theta_{ij}^{+1} \leq \lambda' Y^{t+1}
\]

Such that

\[
\lambda' X^{t+1} \leq x^{+1}
\]

\[
\lambda \geq 0
\]

\[
D_0^1(x^{+1}, y^{+1})^{-1} = \max_{\theta, \lambda} \theta
\]

\[
\theta_{ij}^{+1} \leq \lambda' Y^{t+1}
\]

Such that

\[
\lambda' X^{t+1} \leq x^{+1}
\]

\[
\lambda \geq 0
\]
B. Data description

In this section, we describe the data resource selected as inputs and outputs. This paper examines energy efficiency of Beijing and its three industries respectively and tries to find which factors drive energy efficiency change.

This paper uses the framework proposed in many literatures based on the conventional neoclassical one-sector aggregate production technology where capital, labour, and energy are treated as inputs. The production function form is

\[ Q = F(L, K, E, t) \]

(1)

where \( Q \) is aggregated output or real GDP; \( K \) is the capital stock; \( L \) is the supply of labour; \( E \) is total energy consumption in aggregated level or industrial energy consumption in disaggregated level, and \( t \) denotes the time period. Data for specific instruction are as follows:

1) Energy consumption

We select Beijing’s total energy consumption, individual energy consumption of three industries from 2000 to 2006. All the data are collected from Beijing Statistical Yearbook in 2007. The unit is 10^4 tce.

2) Captial stock

In order to more accurately reflect the role of capital in total-factor energy efficiency, we select capital stock as input instead of fixed assets investment used usually. The capital stock data is difficult, if not impossible, to obtain. There is not readily available dataset for it, especially for China. More often than not, researchers in China use perpetual inventory method to estimate capital stock of China. Combining with previous achievements, Zhangjun et al (2004) estimated capital stock of Beijing from 2000-2004 according to the constant price of 1952. So, we adopt his capital stock estimation of Beijing. As to capital stocks in 2005 and 2006, we use the same method adopted by Zhangjun to gain. And then, all the data of capital stock are converted according to the constant price of 2000. Being short of industrial capital stock, we use the ratio of industrial fixed assets investment to total fixed assets investment of Beijing to take the place of the ratio of industrial capital stock to total capital stock of Beijing under the hypothesis that the production process is stationary, and then gain industrial capital stock. The unit is 10^5 million yuan.

3) Supply of labour

We select employment number in the current year, and all the data are taken from Beijing Statistical Yearbook in 2008. The unit is 10^2 ren.

4) Output

In order to keep consistency with capital stock, real GDP is converted according to the constant price of 2000. Reference [10] found that neglecting sector heterogeneity can influence on the research results, so it is strongly recommended that sector heterogeneity is accounted for by using individual sector price indices for all relevant sectors instead of one general (GDP) deflator. So, we use price index of agricultural means of production, producer's price index for manufactured products and retail price index as price deflators for the primary industry, the secondary industry and the tertiary industry respectively, and then gain sector GDP. The unit is 10^2 million yuan.

III. CASE STUDIES

A. Total Energy efficiency analysis of Beijing

In this section, we describe how to use the Malmquist productivity index based on DEA. Malmquist index and its decomposition into technical change (TC), technical efficiency change (EC), pure efficiency change (PE) and scale efficiency change (SE) is presented in TABLE I.

<table>
<thead>
<tr>
<th>Year</th>
<th>MPI</th>
<th>TC</th>
<th>EC</th>
<th>PE</th>
<th>SE</th>
</tr>
</thead>
<tbody>
<tr>
<td>2000</td>
<td>1.139</td>
<td>1.139</td>
<td>1.000</td>
<td>1.000</td>
<td>1.000</td>
</tr>
<tr>
<td>2001</td>
<td>1.104</td>
<td>1.104</td>
<td>1.000</td>
<td>1.000</td>
<td>1.000</td>
</tr>
<tr>
<td>2002</td>
<td>0.938</td>
<td>0.938</td>
<td>1.000</td>
<td>1.000</td>
<td>1.000</td>
</tr>
<tr>
<td>2003</td>
<td>1.051</td>
<td>1.051</td>
<td>1.000</td>
<td>1.000</td>
<td>1.000</td>
</tr>
<tr>
<td>2004</td>
<td>1.122</td>
<td>1.122</td>
<td>1.000</td>
<td>1.000</td>
<td>1.000</td>
</tr>
<tr>
<td>2005</td>
<td>1.075</td>
<td>1.093</td>
<td>0.984</td>
<td>1.000</td>
<td>0.984</td>
</tr>
<tr>
<td>2006</td>
<td>1.035</td>
<td>1.068</td>
<td>0.969</td>
<td>1.000</td>
<td>0.969</td>
</tr>
<tr>
<td>mean</td>
<td>1.064</td>
<td>1.072</td>
<td>0.993</td>
<td>1.000</td>
<td>0.993</td>
</tr>
</tbody>
</table>

From TABLE I, the results show that average growth in energy efficiency of Beijing is 6.4%. The average growth rate of total energy efficiency marks positive growth, except 2002. Looking down at breakdown of TFP, it can be seen the technical progress has caused an improvement of 7.2% compared with -0.007% decrease of efficiency change. According to the decomposition of overall efficiency into components-pure technical efficiency change and scale efficiency change, we find that scale efficiency change regressed 0.007% compared with 0 scored by technical efficiency change. The results suggest that on average, the decline of energy efficiency lies in the decrease of technical efficiency which regresses in its performance. All in all, the improvement of energy efficiency benefits from joint functions of various factors. In comparison, technical progress plays a main role. The technical efficiency and scale efficiency are all negative growth since 2005, which becomes the leading cause of the decline of total energy efficiency.

B. Energy efficiency difference analyses of three industries

Energy efficiency changes in three industries are different from TABLE II and Figure 1. Energy efficiency in the primary industry shows negative growth, a decline of 1.8%. According to the decomposition of overall energy efficiency into components-technical change and efficiency change, we can find that the contribution of technical change is 0.3%, whereas efficiency change denotes regress in its performance. Energy efficiency in secondary industry shows rapidest growth compared with other two industries, an improvement of 12.8%. According to the decomposition of overall energy efficiency into components-technical change and efficiency change, we...
can find that the contribution of technical change is 12.8%, whereas energy efficiency is constant. Energy efficiency in tertiary industry shows 8.9% growth rate. Like secondary industry, the growth of energy efficiency of tertiary industry is only driven by technical change. In general, secondary industry gives the greatest contribution to the average growth of total energy efficiency and the tertiary industry takes the second place, whereas primary industry shows counteraction.

### TABLE II. Malmquist Index Summary of Three Industries

<table>
<thead>
<tr>
<th></th>
<th>MPI</th>
<th>TC</th>
<th>EC</th>
<th>PE</th>
<th>SE</th>
</tr>
</thead>
<tbody>
<tr>
<td>PI</td>
<td>0.982</td>
<td>1.003</td>
<td>0.980</td>
<td>1.000</td>
<td>1.000</td>
</tr>
<tr>
<td>SI</td>
<td>1.128</td>
<td>1.128</td>
<td>1.000</td>
<td>1.000</td>
<td>1.000</td>
</tr>
<tr>
<td>TI</td>
<td>1.089</td>
<td>1.089</td>
<td>1.000</td>
<td>1.000</td>
<td>1.000</td>
</tr>
<tr>
<td>mean</td>
<td>1.064</td>
<td>1.072</td>
<td>0.993</td>
<td>1.000</td>
<td>0.993</td>
</tr>
</tbody>
</table>

Notes: PI, SI and TI denote primary industry, secondary industry and tertiary industry respectively.

Figure 1. Malmquist index and its composition of three industries

### IV. CONCLUSION

In this paper, we analyze total energy efficiency and individual energy efficiency of three industries during the period 2000-2006 within the framework of Malmquist productivity index based on DEA. This has allowed us to analyze the sources of any change which occurred in the energy efficiency.

In general, the total energy efficiency of Beijing over the period of 2000-2006 experienced growth except 2002. We also find that technical progress contributes to positive function, whereas scale efficiency contributes to negative function. By the analysis of energy efficiency of three industries, we can find that Energy efficiency in secondary industry shows rapidest growth compared with other two industries, whereas the energy efficiency of primary industry deterioration in its performance. The research results can provide some useful information for setting energy policy and industry structure adjustment.

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