Empirical Study on Total Factor Productive Energy Efficiency in Beijing-Tianjin-Hebei Region—Analysis based on Malmquist Index and Window Model

Qiang Xu¹, ², Shuai Ding¹, * and Jingwen An¹

¹School of Management, China University of Mining and Technology, Beijing 100083, China
²Beijing Municipal Science & Technology Commission, Beijing 100195, China

*corresponding author e-mail: dsahau@yeah.net

Abstract. This paper studies the energy efficiency of Beijing-Tianjin-Hebei region and finds out the trend of energy efficiency in order to improve the economic development quality of Beijing-Tianjin-Hebei region. Based on Malmquist index and window analysis model, this paper estimates the total factor energy efficiency in Beijing-Tianjin-Hebei region empirically by using panel data in this region from 1991 to 2014, and provides the corresponding political recommendations. The empirical result shows that, the total factor energy efficiency in Beijing-Tianjin-Hebei region increased from 1991 to 2014, mainly relies on advances in energy technology or innovation, and obvious regional differences in energy efficiency to exist. Throughout the window period of 24 years, the regional differences of energy efficiency in Beijing-Tianjin-Hebei region shrank. There has been significant convergent trend in energy efficiency after 2000, mainly depends on the diffusion and spillover of energy technologies.

1. Introduction

Energy is the fundamental driving force of the world economy and development and is the material basis for human survival. Under the rapid development of the whole world, the development of energy and the protection of environment are the focus of mutual attention of the whole world and of all mankind, this is also one of the most important issues facing China's transformation of economic development mode. According to the 2012 “BP world energy statistics yearbook”, in 2010, China's energy consumption per unit of GDP was 0.63 tons of standard oil/thousand dollars, it's 2.5 times the world average. From this index, Italy has the highest energy efficiency (lowest energy consumption intensity), only 0.18 tons of standard oil/thousand dollars. That means, to create the same economic benefits, Italy’s energy consumption is about a third of our energy consumption. The 13th five-year plan refers to the major goals and basic concepts of economic and social development, in particular, it emphasizes “the development and utilization efficiency of energy resources has been greatly improved. Energy and water consumption, construction land and total carbon emissions are effectively controlled”. Therefore, to study the energy efficiency of Beijing-Tianjin-Hebei region, and find the change in energy efficiency, has practical significance to improve the economic development quality in Beijing-Tianjin-Hebei region.

2. Literature review
The existing literature of research on energy efficiency is quite fruitful. Qu Xiaoe (2009) empirically measured the total factor energy efficiency and technological progress and technical efficiency index in 30 provinces in China from 1990 to 2006. The conclusion shows that, structural adjustment, technological progress and energy price increase have positive effects on energy efficiency improvement [1]. Wang Qunwei et al. (2010) studied the spatial and temporal variation characteristics of energy utilization level in China through the total factor energy efficiency, research shows that, the difference of China’s regional energy efficiency is remarkable, technological progress, pure technical efficiency and scale efficiency are of great importance to the improvement of energy efficiency [2]. Li Lanbing (2012) based on the dual view of management and environment, applied the DEA four-stage model to analyze the energy efficiency of China’s provincial-level regions from 2005 to 2009. The conclusion shows that, the total factor energy efficiency in China is still at a low level in general [3]. Cheng Yuhong and Zhang Weiqi (2013) used panel data from 21 cities in Guangdong province from 2005 to 2010, empirically analyzed the characteristics of the total factor energy efficiency, research shows that, there are obvious regional differences in total factor energy efficiency, the urban economic development level has uncertainty relationship on the total factor energy efficiency [4]. Yang Lili et al. (2014) used the stochastic frontier analysis method to measure the industrial total factor energy efficiency growth rate in the 14 representative cities of 2001 to 2009. The conclusion shows that, the scale of enterprises, opening to the outside world, government intervention, foreign direct investment and the proportion of coal consumption have a significant inhibitory effect on the industrial total factor energy efficiency growth [5]. Chen Guanjv (2014) used random frontier production technology to measure the total factor energy efficiency of 30 industries of China’s manufacturing industry, research shows that, the energy efficiency level between industries is quite different [6].

Based on the above research results, in consideration of the difference in energy efficiency in Beijing-Tianjin-Hebei region, it is not appropriate to assume uniform production functions. Therefore, the paper uses the Malmquist index and Window Analysis (WA) model method based on DEA, uses the panel data from 1991 to 2014, changes and decomposes energy efficiency in Beijing-Tianjin-Hebei region, and finds trends in energy efficiency in order to obtain some valuable conclusions and to give corresponding policy suggestions.

3. Research methods, variables and data processing

3.1. Research method

The Malmquist index method is defined based on the distance function. The linear optimization method is used to measure the efficiency change and technological progress. The change of Malmquist index is the change of total factor productivity (TFP). Under time t’s technical conditions, the Malmquist index based on the output Angle can be expressed as:

\[ M_{o}^{t} = \frac{D_{o}^{t}(x^{t-1}, y^{t+1})}{D_{o}^{t}(x^{t}, y^{t})} \]  

(1)

In formula (1), \( D_{o}^{t} \) is distance function, the subscript \( o \) represents the distance function based on output, \( x \) and \( y \) are inputs and outputs. In the same way, under time \( (t+1) \)'s technical conditions, the Malmquist index based on the output Angle can be expressed as:

\[ M_{o}^{t+1} = \frac{D_{o}^{t+1}(x^{t+1}, y^{t+1})}{D_{o}^{t+1}(x^{t}, y^{t})} \]  

(2)

When the index is greater than 1, the total factor productivity of the period from \( t \) to \( (t+1) \) is increasing, as shown in formula (3):
$$M_o (x^{t+r}, y^{t+r}, x^t, y^t) = \left[ \frac{D_o^t (x^{t+r}, y^{t+r})}{D_o^t (x^t, y^t)} \times \frac{D_o^{t+1} (x^{t+r}, y^{t+r})}{D_o^{t+1} (x^t, y^t)} \right]^{1/2} \times \frac{D_o^{t+1} (x^{t+r}, y^{t+r})}{D_o^{t+1} (x^t, y^t)} = \text{TE} \times \text{TP} = \text{PE} \times \text{SE} \times \text{TP} = \text{TFP}$$

The window model is a dynamic efficiency analysis model for panel data based on the traditional DEA model. Window analysis is operated under the principle of moving average. First, select the window width \(d\) of the study. Charnes et al. (1994) think, choosing window width \(d = 3\) or \(d = 4\) can achieve the best balance in the stability and reliability of the efficiency measure [7]. The window model can dynamically evaluate the relative efficiency of a decision unit, monitor its performance, and provide a basis for managers to make effective decisions [8].

3.2. Variable selection and data processing

Based on traditional economic growth theory, the article selects capital stock (K), human capital stock (L) and total energy consumption (E) as input variables, selects the gross domestic product (GDP) as the output variable, measured and analyzed the total factor energy efficiency in Beijing-Tianjin-Hebei region from 1991 to 2014. Data is from “China energy statistical yearbook”, “China statistical yearbook”, “Beijing statistical yearbook”, “Tianjin statistical yearbook”, “Beijing economy yearbook” and “China statistical data collection” in related years. The variable indexes of input and output are selected as follows:

1) Capital stock (K). According to the existing literature, in this paper, the capital stock of Beijing-Tianjin-Hebei region is estimated by using the popular “perpetual inventory method” (Goldsmith, 1951), which is widely adopted by scholars. The calculation method is: \(K_{i,t} = I_{i,t} + (1 - \sigma_i) K_{i,t-1}\) Among them, \(K_{i,t}\) is the capital stock of \(t\) years in \(i\) region. \(I_{i,t}\) is the investment of \(t\) years in \(i\) region. \(\sigma_i\) is the depreciation rate of fixed assets in \(i\) region. This paper is based on 1990 price base period, and uses the regional fixed asset price index to reduce, removes price factor fluctuations; uses regional fixed capital formation to represent investments \(I_{i,t}\), fixed assets depreciation rate \(\sigma_i\) uses 9.6%.

2) Human capital stock (L). From the previous literature, the researchers use average educational year index to measure human capital stock. It has certain representativeness. Therefore, this paper chooses “average educational year” to reflect the human capital stock in Beijing-Tianjin-Hebei region. Among them, the university graduation education years are 16 years, high school graduation are 12 years, junior high school graduation are 9 years, primary school graduation are 6 years.

3) Total energy consumption (E). This paper uses the total energy consumption in Beijing-Tianjin-Hebei region.

4) The gross domestic product (GDP). This paper is based on the real GDP of Beijing-Tianjin-Hebei region, reduces the price factor by reducing the price of GDP which is based on 1990 price base period.

4. The empirical analysis

4.1. DEA-Malmquist analysis

In order to explore the intrinsic factor of the total factor energy efficiency in Beijing-Tianjin-Hebei region, this article uses the DEAP 2.1 software package to estimate the total factor energy efficiency (TFEE) in Beijing-Tianjin-Hebei region from 1991 to 2014, and decomposes it into the energy efficiency change index (TEE) and the energy technology progress index (TPE). TEE can be decomposed into the energy pure technology efficiency change index (PEE) and energy scale efficiency change index (SEE). The results are shown in Table 1.
Table 1. Change and decomposition of total energy efficiency in Beijing-Tianjin-Hebei region

| YEAR   | TFEE  | TEE  | TPE  | PEE  | SEE  |
|--------|-------|------|------|------|------|
| 1991-1992 | 1.036 | 0.987 | 1.049 | 1.000 | 0.987 |
| 1992-1993 | 1.023 | 1.005 | 1.018 | 1.000 | 1.005 |
| 1993-1994 | 1.045 | 1.005 | 1.040 | 1.000 | 1.005 |
| 1994-1995 | 1.016 | 1.000 | 1.016 | 1.000 | 1.000 |
| 1995-1996 | 1.038 | 1.011 | 1.027 | 1.000 | 1.011 |
| 1996-1997 | 1.048 | 1.000 | 1.048 | 1.000 | 1.000 |
| 1997-1998 | 1.023 | 1.000 | 1.023 | 1.000 | 1.000 |
| 1998-1999 | 1.021 | 1.000 | 1.021 | 1.000 | 1.000 |
| 1999-2000 | 0.985 | 1.000 | 0.985 | 1.000 | 1.000 |
| 2000-2001 | 1.017 | 1.000 | 1.017 | 1.000 | 1.000 |
| 2001-2002 | 1.013 | 1.000 | 1.013 | 1.000 | 1.000 |
| 2002-2003 | 1.015 | 1.000 | 1.015 | 1.000 | 1.000 |
| 2003-2004 | 0.997 | 1.000 | 0.997 | 1.000 | 1.000 |
| 2004-2005 | 1.012 | 1.000 | 1.012 | 1.000 | 1.000 |
| 2005-2006 | 1.020 | 1.000 | 1.020 | 1.000 | 1.000 |
| 2006-2007 | 1.010 | 1.000 | 1.010 | 1.000 | 1.000 |
| 2007-2008 | 1.031 | 1.000 | 1.031 | 1.000 | 1.000 |
| 2008-2009 | 1.022 | 1.000 | 1.022 | 1.000 | 1.000 |
| 2009-2010 | 1.031 | 1.000 | 1.031 | 1.000 | 1.000 |
| 2010-2011 | 1.006 | 1.000 | 1.006 | 1.000 | 1.000 |
| 2011-2012 | 1.004 | 1.000 | 1.004 | 1.000 | 1.000 |
| 2012-2013 | 1.043 | 1.000 | 1.043 | 1.000 | 1.000 |
| 2013-2014 | 0.992 | 1.000 | 0.992 | 1.000 | 1.000 |
| MEAN    | 1.019 | 1.000 | 1.019 | 1.000 | 1.000 |

In terms of time, the average total factor energy efficiency index of Beijing-Tianjin-Hebei region from 1991 to 2014 was 1.019, it has already on the frontier of energy efficiency, its average growth rate is 1.9% (The total factor energy efficiency index minus 1 is the growth rate (Fare, etc., 1994) [9]), so the level of total factor energy efficiency is rising. We can see from the further breakdown of the TFEE index, the average growth rate for TPE in the same period was 1.9%, TEE didn’t change. Therefore, the total factor energy efficiency of Beijing-Tianjin-Hebei region depends mainly on technological progress or innovation.

From the regional dimension, as shown in table 2, the highest total energy efficiency index of Beijing was 1.029, its growth rate was 2.9%. Tianjin was second to 1.015, its growth rate was 1.5%. Hebei is 1.014, but it also grew by 1.4%. It can be seen that, the increase and decrease of total factor energy efficiency in both cities and provinces is mainly due to technological progress. Therefore, accelerating the technological progress and enhancing the capacity of independent innovation is the main way to improve the total factor energy efficiency in Beijing-Tianjin-Hebei region.

Table 2. The average change and decomposition of total factor energy efficiency in Beijing-Tianjin-Hebei region

| REGION            | TFEE  | TEE  | TPE  | PEE  | SEE  |
|-------------------|-------|------|------|------|------|
| Beijing           | 1.029 | 1.000| 1.029| 1.000| 1.000|
| Tianjin           | 1.015 | 1.001| 1.014| 1.000| 1.001|
| Hebei             | 1.014 | 1.000| 1.014| 1.000| 1.000|
| Beijing-Tianjin-Hebei | 1.019 | 1.000| 1.019| 1.000| 1.000|

4.2. DEA window analysis

In order to further analyze the differences and trends of energy efficiency in Beijing-Tianjin-Hebei region, this article uses the DEA - Solver Pro5.0 software package, selecting window width d = 3, that
is to say 3 years to make up a time window, under BCC model based on input angle, and calculates the average efficiency of the windows energy efficiency in Beijing-Tianjin-Hebei region.

Overall, the energy efficiency of Beijing-Tianjin-Hebei region shows obvious differences in different window periods. Specific, the regions with the highest energy efficiency in the window 1-10 are all Hebei, the average efficiency of windows 1, 2, 5, 6 and 7 has reached 1. The highest average efficiency of window 11 is Beijing (0.9994). The highest average efficiency of window 12-13 is Hebei. The efficiency values are 0.9994 and 0.9998 respectively. The highest average efficiency of window 14 is Tianjin (0.9998). The highest average efficiency of window 15 is Tianjin and Hebei, the efficiency value is 1. The highest average efficiency of window 16-17 is Tianjin, the efficiency values are 0.9995 and 1 respectively. The highest average efficiency of window 18 is Beijing (1). The highest average efficiency of window 19 is Hebei (0.9967). The highest average efficiency of windows 20 is Tianjin and Hebei, the efficiency value is 1. The highest average efficiency of window 21-22 is Tianjin, the efficiency value is 1.

From the extreme difference, the difference in energy efficiency in Beijing-Tianjin-Hebei region can be reflected from the side of extreme difference of window 1-22. This difference rose from 0.0285 of window 1 to 0.0356 and 0.0296 of windows 6 and 7. They increased by 24.91% and 3.86% respectively. It then drops to 0.0009 of the lowest window 15, the drop was as much as 97.47 percent. Then rise to 0.0016 of window 22, the rise is 77.78%. The overall change in extreme difference was -94.39%. This indicates that the energy efficiency gap among Beijing-Tianjin-Hebei region has been shrinking over the past 24 years.

From the window changes, during 24 years from 1991 to 2014, energy efficiency in Beijing-Tianjin-Hebei region has generally increased, and the mean has increased by 1.05%. The region where energy efficiency has increased most is Beijing, the growth is 2.77%. Next is Tianjin, the growth is 0.54%. But there has been a marked decline in Hebei, the drop is 0.10%. The energy efficiency of Beijing-Tianjin-Hebei region has shown a clear convergence trend since 2000.

5. Conclusions and policy recommendations

5.1. Main conclusions
This paper combines DEA - Malmquist and window analysis model, uses panel data from 1991 to 2014 in Beijing-Tianjin-Hebei region, empirically measures the total factor energy efficiency in Beijing-Tianjin-Hebei region, and carries out the decomposition of the change of total factor energy efficiency, discovers the trend of energy efficiency. The following main conclusions are drawn.

The total factor energy efficiency of Beijing-Tianjin-Hebei region is rising, its average growth rate is 1.9%. It relies mainly on energy technology progress or innovation. From 1991 to 2014, there are regional differences in total energy efficiency in Beijing-Tianjin-Hebei region and it appears fluctuating trend of "first rise and then rise". Among them, the highest total energy efficiency index is Beijing and it is 1.029, its growth rate was 2.9%. Tianjin was second to 1.015, Hebei is 1.014. All the total factor energy efficiency of Beijing-Tianjin-Hebei region has reached the frontier of energy efficiency, and the change is mainly due to technological progress.

There is a convergence trend in energy efficiency in Beijing-Tianjin-Hebei region. Especially since 2000, there is a remarkable trend. During the overall window period 24 years, the stability of energy efficiency in Hebei is better, the fluctuation of energy efficiency of Beijing and Tianjin is more obvious. Among them, Beijing’s energy efficiency’s rise is the highest, which is 2.77 percent. Tianjin comes second with 0.54 percent. The difference in energy efficiency in Beijing-Tianjin-Hebei region is shrinking, relying mainly on the spread and spillover of energy technologies.

5.2. Policy recommendations
Based on the above empirical analysis, this paper gives the following suggestions.

First, technological progress or innovation is the main source of energy efficiency improvement. There are specific ways to accelerate energy technology progress or innovation in
Beijing-Tianjin-Hebei region, such as do well in the introduction and training of energy technology talents, to expand the development and investment of energy technology facilities, and to strengthen the exchanges and cooperation between regional energy technologies.

Second, the upgrading and transformation of industrial structure is an important way to improve energy efficiency, including improving the proportion of the third industry in Beijing-Tianjin-Hebei region and increasing the use of new energy and clean energy.

Third, industrialization, urbanization and low-carbon lifestyle are effective means of improving energy efficiency. Such as improving the quality of infrastructure construction in Beijing-Tianjin-Hebei region, promoting green travel and energy conservation and emission reduction.

Beijing-Tianjin-Hebei region should formulate differentiated energy policies for local conditions, promote innovation in energy systems, adjust the proportion of energy consumption, deepen the reform of energy prices, optimize the allocation of energy resources and build a resource-conserving and environment-friendly society.

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