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Total Factor Energy Efficiency of Yangtze River Delta Region in China

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Abstract: Energy is always the important material for economic growth and social development. A new index of energy efficiency called total factor energy efficiency (TFEE) consists of energy, capital, labor and other input that produce GDP as output. TFEE index is accounted by DEA through multiple input-output frameworks. Malmquist index measures productivity changing in two periods. Then decomposed the Malmquist index into efficiency change (EFFCH) and technical change (TECH) to estimate whether EFFCH or TECH influence TFEE. This paper analyze the energy consumption of two provinces and one city in Yangtze River Delta region, in terms of the quality of energy consumption and intensity of energy consumption. It shows that the increasing rate of energy consumption in the Yangtze River Delta was slowing down by using the absolute quantity of energy consumed in the region and its proportion in the country. Then the total factor energy efficiency of the Yangtze River Delta region was estimated by using the Yangtze River Delta region's energy consumption and economic growth data during from 1992 to 2010, based on DEA-Malmquist. The changes of total factor energy efficiency can be decomposed in energy efficiency and find the energy efficiency trends. The empirical results show that the Yangtze River Delta region, due to technological progress and technical efficiency, pulls together all the elements of energy efficiency. With time as a dimension, from 1992 to 2008, the TFEE is greater than 1, which means that the TFP is increasing and reaches the efficient frontier in the Yangtze River Delta Region. In a deeper analysis, the trend of total factor energy efficiency shows a W pattern, with the high point appearing in 1998 and 2007 by 5.4% and 5.2% respectively. And the main cause is the technical progress. With region as a dimension, from 1992 to 2008, the TFEE of the provinces and one city in the Yangtze River Delta Region are greater than 1. It indicates that the TFE climbs and reaches the efficient frontier. However, in Shanghai the TFEE is 1.060 which is the highest, followed by Jiangsu and Zhejiang.

Keywords: Energy consumption, Economic growth, Energy efficiency, DEA-Malmquist

1. Introduction

Delta Region is lack of energy, coal, crude oil, natural gas and other energy all transfer from other regions. Sustainable development of this region will be constrained by excessive energy consumption

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and highly extroverted dependence of energy. So, it is important that transit model of economic growth by improving energy efficiency.

The energy efficiency improvement stimulates by total factor productive improvement. However, conditional energy efficiency index that ignores other important input, such as capital and labor, treated energy as the only input to produce GDP. The new index of energy efficiency called total factor energy efficiency (TFEE) consists of energy, capital, labor and other input that produce GDP as output. TFEE index is accounted by DEA through multiple input-output frameworks. According to improvement of DEA, Bauer and Fare (1990,1994) constructed Malmquist index to measure productivity changing in two periods. Then decomposed the Malmquist index into efficiency change (EFFCH) and technical change (TECH) to estimate whether EFFCH or TECH influence TFEE.

Energy is always the important material for economic growth and social development. It provides not only an important source of power for life and production, but also important industrial raw materials. Our study concentrates on energy efficiency of Yangtze River Delta Region where further improvement is planned and executed pressingly. And this paper organizes as follows. Section 2 according to statistic describing the relationship between the economic growth and energy c

aEnergy also plays an important role in the promotion of technological progress, improvement of economic efficiency and the promotion of economic development. China is the second largest producer and consumer of energy. Statistics shows that China's energy consumption and GDP are growing in the same direction. Table 1 shows the average annual growth rate of GDP and energy consumption.

From 1990 to 2008, the economy of the Yangtze River Delta grew dramatically, with real GDP (year 1990=100) increased from 3,102,850 million RMB to 10.169,790 million RMB and with the average annual growth rate of 12.72%. The statistic data shows that energy consumption grows in the same direction with the growth of GDP.

Table 1 the average annual growth rate of GDP and energy consumption
Unit: %

	1990-2008	1990-2000	2000-2008
GDP	<i>12.72</i>	<i>12.57</i>	<i>11.40</i>
EC	<i>7.16</i>	<i>4.49</i>	<i>9.66</i>
GDP/EC	<i>1.78</i>	<i>2.80</i>	<i>1.18</i>

Note: EC is the total energy consumption. Total energy consumption in the Yangtze River is the sum of the consumption of Shanghai, Jiangsu, Zhejiang. Date Source was calculated from "China Energy Statistical Yearbook", "China Statistical Yearbook", "Shanghai Statistical Yearbook", "Jiangsu Statistical Yearbook", "Zhejiang Statistical Yearbook" of the relevant year (the same as below).

In figure 1, the bar chart indicates an increasing trend of total energy consumption (TEC) in the Yangtze River Delta Region and the line shows a decreasing trend of energy consumption intensity (ECI). Judging from the absolute quantity, total energy consumption has been continually increasing since 1990. Otherwise, in view of relative quantity, energy consumption intensity in Yangtze River Delta Region shows steady decreasing trend.

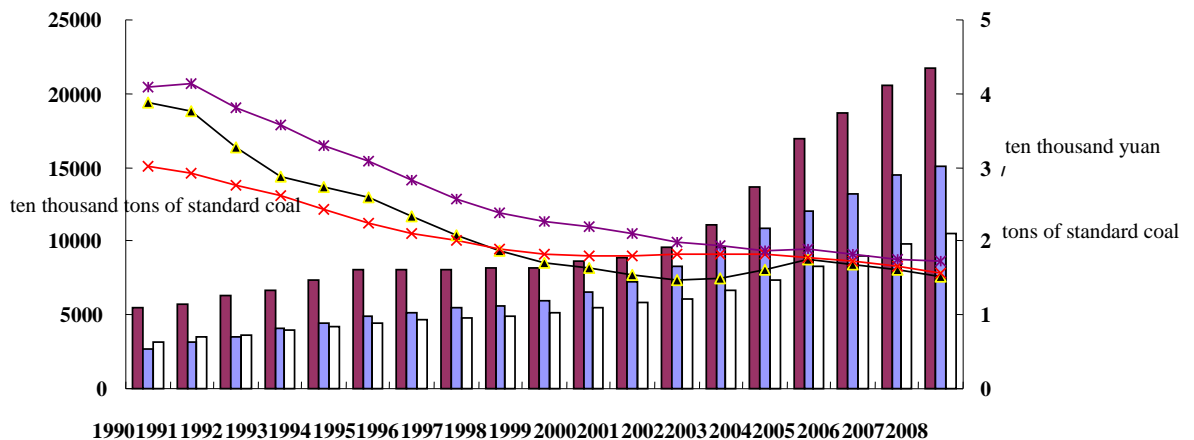


Fig. 1: Total energy consumption and energy consumption intensity in the Yangtze River Delta Region (1990-2008) (year 1990=100)

This paper expects to find the energy efficiency trends. We analyze the energy consumption of two provinces and one city in Yangtze River Delta region, in terms of the quality of energy consumption and intensity of energy consumption. On one hand, by using the absolute quantity of energy consumed in the region and its proportion in the country, we analyze the basic situation and scale of energy consumption in the Yangtze River Delta. On the other hand, in terms of energy consumption intensity, we analyze the relative relations between energy consumption and economic growth.

2. Theory and Descriptive Data

2.1. Theory

We use model analysis to study panel data during the period of 1992-2008. With DEA-Malmquist productivity change index, we measure the TFEE in the Yangtze River Delta Region to decompose energy efficiency change and capture the changing trend of energy efficiency. Then we investigate the way to reduce energy consumption.

The output-based Malmquist productivity change index is defined as the geometric mean of two Malmquist productivity index shown as follows:

$$M_0(x_t, y_t, x_{t+1}, y_{t+1}) = \left[\frac{D_0^{t+1}(x_{t+1}, y_{t+1})}{D_0^{t+1}(x_t, y_t)} \times \frac{D_0^t(x_{t+1}, y_{t+1})}{D_0^t(x_t, y_t)} \right]^{\frac{1}{2}} \quad (1)$$

This equation represents the productivity of the production point (x_{t+1}, y_{t+1}) relative to (x_t, y_t) , while D_0^t and D_0^{t+1} are distance functions in period t and t+1 respectively as technology level in t period as a benchmark. A value greater than 1 indicates positive TFP growth in period t+1. When performance deteriorates over time, the Malmquist index will be less than 1.

Equation (1) can be rewritten as

$$M_0(x_t, y_t, x_{t+1}, y_{t+1}) = \frac{D_0^{t+1}(x_{t+1}, y_{t+1})}{D_0^{t+1}(x_t, y_t)} \times \left[\frac{D_0^t(x_{t+1}, y_{t+1})}{D_0^{t+1}(x_{t+1}, y_{t+1})} \times \frac{D_0^t(x_t, y_t)}{D_0^{t+1}(x_t, y_t)} \right]^{1/2} = EFFCH \times TECH \quad (2)$$

Thus total factor productivity change is decomposed into two components: efficiency change (EFFCH) and technical change (TECH). Technical change captures the shift in technology between the two periods. It indicates whether or not technical progress occurs at the input-output combination for a particular region or industry. Efficiency change measures the change in relative efficiency between year t and t+1, which reflects whether production is getting closer to or farther away from the frontier.

2.2. Variable Selection and Data Sources

When estimating the TFEE, we choose the inputs-outputs level of two provinces and a city in the Yangtze River Delta region (Shanghai, Jiangsu and Zhejiang) to analyze technological progress and efficiency of the changes in energy efficiency.

To determine the input-output variables, we choose 3 input indexes; they are capital stock, labor force and total energy consumption in the Yangtze River Delta region. Firstly, K represents capital stock which is estimated by Perpetual Inventory Method with $K_{i,t} = I_{i,t} + (1 - \sigma_i)K_{i,t+1}$. In this equation, $K_{i,t}$ is the capital stock in province i at year t. $I_{i,t}$ is the province's investment in the same year and σ_i is fixed assets depreciation rate in province i. We follow the method of Zhang Jun (2003) and Shan Haojie (2008), convert base year into year 1992, namely 100, and deflate provinces and cities' fixed assets price index to exclude the influence of price fluctuation. $I_{i,t}$ is fixed capital formation with the depreciation rate, by 10.96%. Secondly, L represents labor force, and we use the index of employees' numbers instead. Thirdly, EC (energy consumption) adopts total energy consumption of every provinces and cities. Besides, there is an output index: the actual GDP of the Yangtze River Delta region. To eliminate the price factors' affection, we use GDP of 1992 as the base period to reduce the GDP.

All data are from "Shanghai Statistical Yearbook", "Jiangsu Statistical Yearbook", "Zhejiang Statistical Yearbook" and "China Statistical Yearbook" of the relevant years.

3. Empirical Analysis

With the help of DEAP software by Coelli (1996), we estimate the TFEP in the Yangtze River Delta Region from 1992 to 2008. Then we decompose the TFEP into Malmquist productivity index, efficiency change (EFFCH) and technical change (TECH) which can be decomposed into pure efficiency change index and scale efficiency change index. The result is shown in table 2.

Table 2 Average change and decomposition of Malmquist productivity change index of the Yangtze River Delta Region (1992-2008)

Year	TFEE	EFFCH	TECH	PEFFCH	SEFFCH
1992-1993	<i>1.031</i>	<i>1.018</i>	<i>1.013</i>	<i>1.000</i>	<i>1.018</i>
1993-1994	<i>1.004</i>	<i>0.991</i>	<i>1.014</i>	<i>1.000</i>	<i>0.991</i>
1994-1995	<i>1.005</i>	<i>1.009</i>	<i>0.996</i>	<i>1.000</i>	<i>1.009</i>
1995-1996	<i>1.001</i>	<i>1.023</i>	<i>0.978</i>	<i>1.000</i>	<i>1.023</i>
1996-1997	<i>1.015</i>	<i>1.002</i>	<i>1.013</i>	<i>1.000</i>	<i>1.002</i>
1997-1998	<i>1.054</i>	<i>1.000</i>	<i>1.054</i>	<i>1.000</i>	<i>1.000</i>
1998-1999	<i>1.029</i>	<i>1.000</i>	<i>1.029</i>	<i>1.000</i>	<i>1.000</i>
1999-2000	<i>1.027</i>	<i>1.000</i>	<i>1.027</i>	<i>1.000</i>	<i>1.000</i>
2000-2001	<i>1.022</i>	<i>0.996</i>	<i>1.026</i>	<i>1.000</i>	<i>0.996</i>
2001-2002	<i>1.022</i>	<i>0.992</i>	<i>1.030</i>	<i>1.000</i>	<i>0.992</i>
2002-2003	<i>1.021</i>	<i>0.991</i>	<i>1.030</i>	<i>1.000</i>	<i>0.991</i>
2003-2004	<i>1.015</i>	<i>0.988</i>	<i>1.027</i>	<i>0.986</i>	<i>1.002</i>
2004-2005	<i>1.002</i>	<i>1.019</i>	<i>0.984</i>	<i>1.004</i>	<i>1.014</i>
2005-2006	<i>1.031</i>	<i>1.000</i>	<i>1.032</i>	<i>1.000</i>	<i>1.000</i>
2006-2007	<i>1.052</i>	<i>0.999</i>	<i>1.053</i>	<i>0.999</i>	<i>1.000</i>
2007-2008	<i>1.039</i>	<i>0.999</i>	<i>1.041</i>	<i>1.005</i>	<i>0.993</i>
Average Value	<i>1.023</i>	<i>1.002</i>	<i>1.021</i>	<i>1.000</i>	<i>1.002</i>

The average of total factor energy efficiency in Yangtze River Delta region is 1.023 and reaches efficient frontier whose average growth rate was 2.3% (according to Fare et al, the total factor energy efficiency reducing one is the growth rate), which means that the level of total factor energy efficiency is rising. By

further decomposing TFP, we can see the average growth rate of technological progress in the same period is 2.1%; the average growth rate of technological efficiency change is 0.2%; and the average growth of TFP driven by technological progress and technological efficiency is positive. The last two columns of table1 decompose efficiency change index into PECH and SCH, which means that the gap between producer and the level of cutting-edge technology is narrowing. In one word, total factor energy efficiency is spurred by technical progress and technical efficiency, however, the contribution of technical progress is larger than that of technical efficiency.

With time as a dimension, from 1992 to 2008, the TFEE is greater than 1 which means that the TFP is increasing and reaches the efficient frontier in the Yangtze River Delta Region. Moreover, the trend of TFEE shows a W pattern, of which the highest average growth rate appears in 1998 and 2007, reaching 5.4% and 5.2% respectively. And the growth can be explained by technical progress. From 1992 to 1998, caused by technical regress, the total factor energy efficiency shows a decreasing trend. Especially, from 1994 to 1996, the annual average growth rates of total energy efficiency are negative value. And then, from 1998 to 2006, caused by technical efficiency retrogression, total factor energy efficiency has decreased. Especially, from 2000 to 2004, the growth rate is negative value. So, there are different reasons behind the W pattern of total factor energy efficiency in the Yangtze River Delta Region.

Table 3 Average change and decomposition of Malmquist productivity change index of the Yangtze River Delta Region

Region	TFEE	EFFCH	TECH	PEFFCH	SEFFCH
Shanghai	1.060	1.000	1.060	1.000	1.000
Jiangsu	1.009	1.008	1.001	1.000	1.008
Zhejiang	1.001	0.997	1.004	0.999	0.998
the Yangtze River Delta Region	1.023	1.002	1.021	1.000	1.002

With region as a dimension, from 1992 to 2008, the TFEE, the provinces and one city in the Yangtze River Delta Region, is greater than 1 (Table 2). It indicates that the TFE climbs and reaches the efficient frontier. However, TFEE in Shanghai is 1.060, which is the highest, followed by Jiangsu and Zhejiang. Moreover, decomposition of TFEE varies in different regions. Technical progress pulls the TFEE of Shanghai where average growth rate of technical progress is 6%, with no change in technical efficiency. In Jiangsu, the average growth rate of technical progress is 0.1% and the average growth rate of technical efficiency is 0.8%, so efficiency change pulls the TFEE. In Zhejiang, technical progress is the reason of the rising of TFEE. The average growth rate of technical progress is 0.4% and the average growth rate of technical efficiency is -0.3%, which is decomposed into the growth rate of pure efficiency change (-0.1%) and the growth rate of scale efficiency change (-0.2%). With the higher growth rate of technical progress, the TFEE reaches the efficient frontier. In short, although TFEE in Yangtze River Delta Region all reaches the efficient frontier, the contribution of the factors has their own regional effects.

4. Conclusions and Implications

Based on DEA-Malmquist productivity index, this paper estimates the total factor energy efficiency of Yangtze River Delta region empirically by using the data of energy consumption and economic growth in this region from 1992 to 2008, and we decompose the changes in energy efficiency and find the energy efficiency trend. We find that technological progress and technical efficiency pull the total factor energy efficiency together, but technical progress has high contribution rate than efficiency change. With time as a dimension, from 1992 to 2008, the TFEE is greater than 1, which means that the TFP is increasing and reaches the efficient frontier in the Yangtze River Delta Region. In a deeper analysis, the trend of total factor energy efficiency shows a W pattern, with the high point appearing in 1998 and 2007 by 5.4% and 5.2% respectively. And the main cause is the technical progress. With region as a dimension, from 1992 to 2008,

the TFEE of the provinces and one city in the Yangtze River Delta Region are greater than 1 (Table 2). It indicates that the TFE climbs and reaches the efficient frontier. However, in Shanghai the TFEE is 1.060 which is the highest, followed by Jiangsu and Zhejiang.

Based on the above empirical analysis, we get three enlightenments. Firstly, we should improve energy efficiency. In this way we can relieve the pressure economic development puts on energy consumption. Secondly, we should change the mode of economic development by adjusting the economic structure and energy structure. In terms of economic structural adjustment, we should control energy inputs intensity, lower the consumption of unit energy, and promote the rational development and utilization of energy. In terms of the energy consumption structure, while reducing energy consumption and improving energy using efficiency, we also need to actively develop new energy. Thirdly, we should promote the technology of using energy and improve the efficiency of using energy. We should establish a market-oriented operation mechanism of energy conservation and carry on the exploration and tryout of low carbon economy applied in the core business sector of an enterprise. We should reinforce the implementation of the projects of energy conservation in Yangtze River Delta region.

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