Research on the Total Factor Productivity in China’s Electric Power Industry Based on the GML Model

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Abstract. This paper uses the Global Malmquist-Luenberger index to measure the total factor productivity (TFP) in China's electric power industry of its 30 provinces during 2007-2013 with $SO_2$, $NO_x$ and soot emissions in the thermal power industry as the undesirable outputs, and decomposes the total factor productivity into technological progress, the pure technical efficiency and scale efficiency changes. The research shows that the total factor productivity improvement of the electric power industry is more noticeable, but the growth rate is not stable; the technological progress is the main cause of the growth rate increase in the provincial total factor; the contribution of scale efficiency is higher in the provinces with their TFP growth rate in the top, and pure technical efficiency deteriorates seriously in the provinces with their TFP growth rate in the bottom.

Introduction

In recent years, with the rapid development of power industry, the situation of serious power shortage as a long-term problem to the national economy gets basically solved. However, when the coal combustion releases heat energy, the pollutants (such as sulfur dioxide, nitrogen oxides and dust) caused by it have brought a series of environmental problems because that our country’s power plants give priority to coal-fired thermal power units. Therefore, only by further improving the production efficiency of the power industry does the electric power industry meet the demand of economic development, and it reduces one-time energy consumption and environmental pollution in power production at the same time.

Numerous scholars have done a lot of researches on undesirable output brought by pollution to the environment with total factor productivity as one of the important indices for evaluation of the production efficiency of electric power enterprises. Fare (1985) \cite{1} used DEA model to evaluate the relative technical efficiency of the state-owned power plants and private power plant for the first time. Hereafter, the model was widely applied in terms of technical efficiency evaluation of the electric power industry, and gradually became the most effective and the most commonly used nonparametric method. Internationally, Yang (2010) \cite{2}, Kwoka (2010) \cite{3}, Sueyoshi [4] (2012) and Song (2013) \cite{5} measured the environmental performance of electric power industry respectively with the use of the DEA method. In China's latest research, Wang Juan and Zheng Haoyuan (2015) \cite{6} used the method of Malmquist-Luenberger productivity index to measure the total factor productivity in electric power industry of China’s 30 provinces during 2001-2012 with the $SO_2$ emission as the undesirable output. The results showed that technological progress was the major driving force to increase the total factor productivity. Zhao Tianyan et al. (2015) \cite{7} used SBM directional distance function to measure the environmental total factor productivity of China’s ten listed thermal power enterprises during 2009-2013, and the results showed that environmental technical efficiency and technical progress were the major driving forces to increase enterprises’ environmental total factor productivity.
The literature above measured the total factor productivity of the power industry mainly from ML productivity index to provide a lot of reference for this paper. Although it can measure total factor productivity incorporating the undesired output, ML productivity index used in the existing literature basically adopted geometric mean form of two current ML productivity indices, which probably led to the linear programming problem without a solution and thereby resulted in ML productivity index without circularity and transitivity in measuring intertemporal directional distance function. Therefore, this paper uses the Global Malmquist-Luenberger (GML) productivity index built by Oh (2010) [8], which can not only deal with multiple input and multiple output, solve the problems of environmental pollution undesirable output caused by production, also can effectively avoid the linear programming problem without a solution to realize cycle accumulation. This paper further decomposes GML index into pure technical efficiency change, scale efficiency change and technical progress, and provides some useful reference for China's thermal power industry (specific) by measuring the total factor productivity of the thermal power industry in China's 30 provinces and cities during 2007-2013.

**Research method**

**Directional environmental distance function model.** This paper builds an environmental technology set of the thermal power industry including both desirable output and undesirable output. With the thermal power industry in each province regarded as a decision-making unit to construct, this paper assumes that each decision-making unit uses N kinds of input $x = (x_1, x_2, \cdots, x_n) \in \mathbb{R}^N_+$, to obtain M kinds of desirable output $y = (y_1, y_2, \cdots, y_n) \in \mathbb{R}^M_+$ and I kinds of undesirable output $b = (b_1, b_2, \cdots, b_n) \in \mathbb{R}^I_+$, and $P^t(x)$ means potential collection in the period of $t = 1, \cdots, T$:

$$P^t(x) = \{(y^t, b^t): x^t \text{produce}(y^t, b^t)\}, x \in \mathbb{R}^N_+$$

(1) Formula (1) must meet four conditions: the feasible set is a closed and convex one; the desirable output and input are disposed at will; the undesirable output is at weak disposal; the desirable output and undesirable output have zero correlation.

Although it is conducive to understand the related concepts, to build the environmental technology set is not highly correlated to computation. Directional distance function can well solve the problem containing evaluation of the undesirable output efficiency based on Luenberger (1995) [9] Shortage Function thoughts. Related definitions are listed as follows:

$$\bar{D}^t(x^t, y^t, b^t; g) = \sup\{\beta: (y^t, b^t) + \beta g \in P^t(x^t)\}$$

(2) In the formula (2), $x^t$ is the input vector; and $y^t$ and $g_y$ are the desirable output vectors; $b^t$ and $g_b$ are the undesirable output vectors; $g = (g_y, g_b)$ means a direction vector. This paper hypothesizes $g = (y, -b)$, it means under the condition of a given input $x$, the decrease or increase of the undesirable output is proportional to that of the desired output and $\beta$ is the maximum possible value of the decrease in undesirable output and the increase in desirable output.

**Malmquist-Luenberger index.** According to the method proposed by Chung et al. [10], the directional distance function incorporating the undesirable output is applied to Malmquist model, and the obtained Malmquist index becomes Malmquist-Luenberger productivity index. Namely, Malmquist indices obtained from any Malmquist model incorporating the undesirable output might be called the Malmquist-Luenberger indices. See formula (3).

$$ML_{t+1}^t = \left[\frac{1+\beta^t(x^t, y^t, b^t; y^t, -b^t)}{1+\beta^t(x^t, y^t, b^t; y^t, -b^t)} \times \frac{1+\beta^{t+1}(x^{t+1}, y^{t+1}, b^{t+1}; y^{t+1}, -b^{t+1})}{1+\beta^{t+1}(x^{t+1}, y^{t+1}, b^{t+1}; y^{t+1}, -b^{t+1})}\right]^{1/2}$$

(3) The total factor productivity growth index considering the environmental factors can be used for Malmquist-Luenberger (ML) index based on the output orientation. ML productivity is decomposed into two parts: technical change (TC) index and efficiency change (EC) index.
Among them, $\bar{D}_t(x^t, y^t, b^t; y^t, -b^t)$ and $\bar{D}_t^1(x^{t+1}, y^{t+1}, b^{t+1}; y^{t+1}, -b^{t+1})$ mean the efficiency value of the period $t$ of decision making unit in the periods of $t$ and $t+1$ respectively; $\bar{D}_t^1(x^t, y^t, b^t; y^t, -b^t)$ and $\bar{D}_t^1(x^{t+1}, y^{t+1}, b^{t+1}; y^{t+1}, -b^{t+1})$ mean the efficiency value of the period $t+1$ of decision making unit in the periods of $t$ and $t+1$ respectively; ML, TC and EC greater than (less than) 1 respectively shows the increase (decrease) in the total factor productivity, technical progress(retrogress) and efficiency improvement (deterioration).

**Global-Malmquist-Luenberger index.** Oh built the Global-Malmquist-Luenberger (GML) index on the basis of ML index. Because the evaluated decision making units must be included in the global reference set, the problem of VRS model without feasible solution does not exist in the GML index, and the occurrence for the phenomenon of "backward" technology is also avoided. GML productivity index is as follows:

$$GML = \frac{1 + \bar{D}_t(x^t, y^t, b^t; y^t, -b^t)}{1 + \bar{D}_t^1(x^{t+1}, y^{t+1}, b^{t+1}; y^{t+1}, -b^{t+1})}$$

In this paper, GML index is decomposed into pure technical efficiency change (GEC), scale efficiency change (GPC) and technology change (GTC) under the condition of invariable in scale reward.

$$GML = GPC \times GEC \times GTC$$

$$GPC_{t+1} = \frac{1 + \bar{D}_t^p(x^t, y^t, b^t; y^t, -b^t)}{1 + \bar{D}_t^{p+1}(x^{t+1}, y^{t+1}, b^{t+1}; y^{t+1}, -b^{t+1})}$$

$$GEC_{t+1} = \frac{1 + \bar{D}_t^g(x^t, y^t, b^t; y^t, -b^t)}{1 + \bar{D}_t^{g+1}(x^{t+1}, y^{t+1}, b^{t+1}; y^{t+1}, -b^{t+1})}$$

$$GTC_{t+1} = \frac{1 + \bar{D}_t^t(x^t, y^t, b^t; y^t, -b^t)}{1 + \bar{D}_t^{t+1}(x^{t+1}, y^{t+1}, b^{t+1}; y^{t+1}, -b^{t+1})}$$

Thereinto, the directional distance function is $\bar{D}_t^p(x^t, y^t, b^t; y^t) = \max\{\beta: (y^t, b^t) + \beta g^t \in P^g(x^t)\}$; GML, GEC, GPC, GTC greater than (less than) 1 respectively indicates that the increase in the environmental total factor productivity (the decrease in the global total factor productivity), improvement of pure technical efficiency (deterioration of pure technical efficiency), rising scale efficiency (dropping scale efficiency) and technical progress (retrogress).

**Data selection and processing**

The total factor productivity with the undesirable outputs (such as SO2, NOx and soot emissions) in the power industry as constraint conditions is measured and decomposed in the decision-making unit of China's 30 inland provinces (without consideration of Tibet due to the incomplete data) during 2007-2013. Data used are obtained by organizing China Electric Power Yearbook, China Statistical Yearbook on Environment, China Industry Economy Statistical Yearbook and Annual Report on Environment in China over the years.

The paper selects related data of thermal power industry. However, relative to the data of the overall power generation industry, the data of thermal power industry are relatively hard to be
available. The paper selects two input indices, a desirable output index and three undesirable output indices through organization and calculation.

Input variables: Coal consumption: Because the energy consumption in thermal power industry comes mainly from coal, and pollutants are mainly from the burning of coal too, this paper takes the coal quantity as input variables; Installed capacity: Due to the difficulty in calculating and access to the capital in the thermal power industry, this paper uses the installed capacity instead of capital investment of the thermal power industry.

Desirable output variable: Generated energy: Zhao Tianyan [7] considered the important indicator to measure the thermal power enterprise output is generated energy, so this paper will take generated energy as the only desirable output variable.

Undesirable output variables: the pollutants in the thermal power industry are mainly SO$_2$, NO$_x$ and soot, so the yearly emissions of SO$_2$, NO$_x$ and soot in the thermal power industry act as the undesirable output variables in this paper.

Empirical analysis

The total factor productivity index based on the Global Malmquist-Luenberger is measured and obtained using the panel data of electric power industry in 30 provinces and cities in our country and maxdeap6.8 pro software. Meanwhile, it is decomposed into technological change, the pure technical efficiency change and scale efficiency change. The rest of the paper will analyze the total factor productivity and its internal sources from two aspects of our country’s electric power industry as a whole as well as provinces and cities in details.

The overall analysis of the power industry

The annual variation trend analysis. As you can see from Figure 1-1, the total factor productivity of the power industry in our country presents growth, there is a stage characteristic of decrease in individual years, growth rate rises from -1.97% during 2007-2008 to 1.25% during 2012-2013 and it is obvious, which shows that in recent years, the upgrading effect of our country’s electric power industry has been obvious, and the industry transformation effect is significant. But at the same time, we see that the growth rate of the total factor productivity is not stable and there was an outstanding growth decline in 2011, which reflects that our country’s electric power industry development is not mature and easily influenced by external factors, and the reform of the supply side needs further strengthening to improve the internal stability of the electric power industry development.

![Figure 1.-1 Annual changes of TFP growth rate in our country’s electric power industry.](image)
power industry is the technology change, and the continuous extension of the production technology frontier of the electric power enterprise is the most important force to promote the growth of total factor productivity. During the period of research, fluctuations in the pure technical efficiency change and scale efficiency change show stability, which periodically influences improvement in development quality of the electric power industry. Specifically, the technology change rate of our country’s electric power industry is -2.85% during 2007-2008 and production technology retrogresses obviously, which counteracts 1.35% growth of the pure technical efficiency and leads to total factor productivity in a range of backwards. Then, the pure technical efficiency is in negative growth for two consecutive years, but the technology change continues to rise, which raises the total factor productivity of the power industry. Although the pure technical efficiency and scale efficiency achieved positive growth in 2011, the total factor productivity is still lowed by the sharp slowdown of the technology change with the growth rate of only 0.28%. The scale efficiency is in continuous decline and the pure technical efficiency also performs poorly in 2012 and 2013, but the technology change is once more than 6%, which raises effectively the total factor productivity. Electric power enterprises in our country should keep the production technology improvement constantly, and at the same time, focus on strengthening efficiency and optimizing the scale to achieve total factor productivity from being driven by a single technology change to the collaborative transformation by the collaboration of technology, efficiency and scale to raise the level of compound growth.

**Comparative analysis of different provinces**

Comparative analysis. There are 5 provinces, growth rates for factor productivity of which are more than 2%. They are Qinghai, Anhui, Tianjin, Beijing and Jiangsu respectively. Wherein, the growth rates of Qinghai and Anhui are even more than or close to the average annual growth rate of 4%. The hoisting speed of overall development quality of the electric power industry in these provinces is higher. There are 9 provinces, growth rates for average annual factor productivity of which are negative. They are Guangxi, Guizhou, Jilin, Liaoning, Shanxi, Ningxia, Yunnan, Sichuan and Guangdong respectively. Retrogressive total factor productivity phenomena of different levels exist in these provinces. Wherein, Guangdong and Sichuan back more than 1% per year. Provinces with backward total factor productivity are mainly concentrated in the northeast, south and southwest of China.
Total factor productivity decomposition analysis in various provinces. The growth rates of the total factor productivity in the electric power industry of 30 provinces and cities in China, and the composition of the situation of its decompositions of technology change, pure technical efficiency change and scale efficiency change are presented in Figure 1-3. You can see that the decomposition achieved positive growth of Qinghai, Anhui, Tianjin Beijing and Jiangsu, growth rates for the total factor productivity of which rank top. The main reason for the total factor productivity growth in most provinces is technology change. Individual provinces and cities have differences, such as the number one, Qinghai province, technology change of which is not obvious, and the improvement of scale is a main basis for the total factor productivity growth. In the provinces and cities ranking in the middle of the total factor productivity growth, the contribution of the scale efficiency change to total factor productivity growth is higher, and Shanghai, Xinjiang and Fujian show such features. In the provinces and cities ranking in the back of the total factor productivity growth, the retrogression of pure technical efficiency constitutes the primary reason of decline in total factor productivity. For example, although the technology change and the scale efficiency in Shanxi Province have positive growth, the pure technical efficiency declines for more than 3%, which leads to reverse situation of the total factor productivity. Jilin, Liaoning, Yunnan, Sichuan and Guangdong also show the similar situation. Therefore, electric power enterprises in different provinces should formulate business strategies based on their own reality, and optimize the path of ascension for the total factor productivity with different emphasis.

The annual change trend of the total factor productivity in typical provinces. This paper chooses five representative provinces and cities (including Beijing, Hebei, Shanghai, Xinjiang and Guangdong), and examines the annual changes in total factor productivity.
Figure 1-5 TFP annual change trends of several typical provinces.

Figure 1-5 shows that there exist certain differences in the total factor productivity change trends of various provinces. Performances of Beijing and Shanghai are similar. The overall change trend shows a "V" type with 2011 at the bottom. Then, it picks up and the whole presents a big leap. Hebei province fluctuates with narrow range within small sections, which is relatively stable. Xinjiang shows "N" type trend, and there is an evident decline in 2011. The total factor productivity of Guangdong province backs seriously in starting years, and then gradually returns to growth. Repair trend occurs after the fall in 2012.

**Result analysis.** Conclusions are drawn through comparative analysis of the electric power industry as whole and different provinces:

(1) During the period of research, the total factor productivity improvements of the electric power industry in our country are more obvious, and the effect of industry transformation is outstanding. However, the total factor productivity growth is not stable. The maturity of the power industry development in our country is not high and it is easily influenced by external factors. The reform of the supply side needs to be further strengthened to improve the internal stability of the electric power industry development.

(2) The main internal driving factor of total factor productivity of the electric power industry in our country is the technology change. The continuous extension of the production technology frontier in the electric power enterprise is the most important force to promote the growth of total factor productivity. The fluctuation in the pure technical efficiency change and scale efficiency change shows stability, which periodically influences the total factor productivity improvement in the electric power industry.

(3) The decompositions of provinces with factor productivity growth ranking top have achieved positive growth, and the source of growth in most provinces is the leap ascension of technology. In the provinces and cities with factor productivity growth in the middle, the contribution of the scale efficiency change on the total factor productivity growth is higher. In the provinces with the total factor productivity in the back, the retrogression of the pure technical efficiency constitutes the primary reason of decline in total factor productivity.

**Summary**

This paper selects related data of the electric power industry in 30 provinces and cities in our country to construct the panel data. The total factor productivity index based on the Global Malmquist-Luenberger is measured and obtained using maxdea6.8 pro software, and is decomposed. The results show that the total factor productivity improvements of the electric power industry in our country are obvious; the technology change is the main cause of the provinces to improve
growth; in the provinces with total factor growth rate ranking top, the contribution of the scale efficiency is higher, and in the provinces with total factor growth rate in the back, the pure technical efficiency is in serious deterioration.

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Reference


