Research on Total Factor Productivity Evaluation of Chinese Power Grid Enterprises

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Abstract. The total factor productivity research on the micro level is to analyze an enterprise’s real input and output, choose an appropriate measurement method, and accurately measure its input-output level. Based on the “three responsibilities” of Chinese power grid enterprises, this paper constructs a systematic and scientific input-output factor screening system, determines specific output and input indicators, uses Törnqvist total factor productivity index model to calculate the TFP change of a certain Chinese power grid enterprise in the year of 2008-2017, does a further penetration analysis of input-output changes, verifying that the evaluation model constructed in this paper is effective.

1. Introduction

Efficient energy production and transmission and reasonable energy price provide a country with the necessary conditions to win an advantage in international competition. Effectively measuring the input-output efficiency of grid companies, promoting efficient investment and lean operations, is in the long-term interest of energy consumers and the country as a whole.

Power grid enterprises generally use traditional indicators such as line loss rate, equipment utilization hours, and labor productivity to measure production efficiency or effectiveness. These indicators can only reflect the progress or shortcomings of the enterprise from one aspect, but not a comprehensive and overall quantitative evaluation [1]. Total factor productivity (TFP) is a better solution to these problems. In terms of methods, TFP evaluation is a comprehensive method based on input and output, and is an important supplement to traditional single factor productivity. The application of TFP evaluation in power grid enterprises is actually a comprehensive comparison of the transmission and distribution services provided by the enterprise with the input capital and labor and other factors. Furthermore, changes in outputs and inputs and how these changes influence TFP will be revealed.

1.1. Related Work

Related works can be divided into two categories: theoretical studies in TFP measurement methods and empirical studies in measurement of power grid enterprises’ TFP.
1.1.1. Theoretical studies in TFP measurement methods. Solow [2] first proposed a specific calculation method of TFP: the production function mainly includes two variables: capital input and labor input. Technical progress is non-embodied. Therefore, we can deduct capital and labor inputs from total output growth and the remaining value that cannot be explained by inputs is TFP.

Since then, scholars from various countries have conducted studies on the estimation of TFP, from the macroeconomic overall level to the microscopic individual enterprise level. The micro-level TFP calculation mainly follows the relative efficiency measurement thinking based on the production frontier. Based on the production characteristics of "multiple inputs and multiple outputs" of common manufacturers, studies done by Farrell [3] used the production frontier to measure the relative input-output efficiency of different manufacturers. According to the different expressions of the distance function, TFP calculation based on the frontier theory can be divided into two categories, namely Data Envelopment Analysis (DEA) [4] and Stochastic Frontier Analysis (SFA) [5].

1.1.2. Empirical studies in measurement of power grid enterprises’ TFP. In Australia and other countries [6], TFP calculation of power grid companies has been effectively applied in practice. For example, the Australian Energy Regulator (AER) uses three top-down benchmarking methods in its annual economic benchmarking report to measure the efficiency of distribution services [7]. This includes a time-series TFP index model and Multilateral TFP (MTFP) model, which link total inputs to total output to compare trends in the overall productivity and efficiency of distribution companies [8].

However in China, the calculation of TFP for grid companies is still in the research and exploration stage. Zhang et al. [1] used the panel data of 24 provincial power companies of the State Grid Corporation of China (SGCC) from 2005 to 2009, and chose the DEA-Malmquist index model to calculate, proving that the TFP of Chinese transmission and distribution network has gradually increased. Lu et al. [9] also used the DEA-Malmquist index model to conduct an empirical analysis of the development efficiency and regional differences of grid companies using the data of 27 provincial power companies from 2010 to 2016, which showed that the industry's TFP is generally at a high level but with a slow decline. Earlier studies also included: Zhao et al. [10] measured the average efficiency of 18 county-level power supply bureaus from 1998 to 2002, and Liang et al. [11] measured the efficiency of 8 provincial transmission and distribution networks from 1995 to 1997.

1.2. Our Contribution

In previous Chinese studies, researchers were mainly subject to two issues. First of all, choice of inputs and outputs is limited by data availability. In that case, it was extremely hard to define the right inputs and outputs reflecting the reality. Furthermore, although DEA is the most popular measurement method in those studies for its convenience and is especially suitable for comparison between companies in the same industry with a large sample, it is far from perfect. In DEA calculation process, the weights of different inputs and outputs, which are crucial for the TFP value, are obtained by automatic planning. This is far from reality, because in the operation and management of power grid enterprises, resource inputs cannot be freely allocated, and outputs cannot be freely adjusted either. Moreover, the calculation process is difficult to perform penetration analysis, which leaves researchers a black box. Even worse, anomalous data is not easy to identify and may distort the efficiency scores.

To address the two issues mentioned above, we drew on the practices of AER and Economic Insights (EI) in the annual benchmarking of Australian distribution and transmission networks [7, 8, 12]. Firstly, an input-output selection framework based on the "three responsibilities" [13] of Chinese power grid companies was constructed. At the same time, in-depth surveys of sample companies were conducted to collect a large amount of production and operation data, which solved the problem of data limitations. In that way, the selection of input-output indicators in this study is scientific and objective, which effectively supports the TFP calculation. Secondly, the Törnqvist index method is used to calculate TFP in this study. By analyzing each input-output factor in detail, the weights of different inputs and outputs are scientifically designed. Not only can we obtain the TFP value and
changes over the years, but we can even decompose TFP, and analyze the causes of TFP changes from the micro perspective of the overall input, output, and specific input-output factors. Therefore, we can locate abnormal data in time. Effectively reflecting the actual situation, the TFP is able to provide decision-makers with conclusions and management advice in line with the real business.

1.3. Paper Structure

The rest of the paper is organized as follows. Section 2 introduces the Törnqvist index model. Section 3 elaborates the input-output factors selected. Section 4 introduces the weights of inputs and outputs. Section 5 shows the TFP calculation results and analysis of a certain Chinese power grid company.

2. Törnqvist Index Model

Generally, what matters for growth is not the value of TFP itself, but the growth rate of TFP. Therefore, the focus of research on TFP should be on the measurement of the growth rate of TFP [14]. In the case of single input and single output, it is easy to measure TFP. But it is more difficult when multiple inputs and multiple outputs are involved. Therefore, an index is introduced here to measure the change of TFP when there are multiple inputs and multiple outputs, which is the Törnqvist TFP index model [15].

\[
\ln(\frac{TPF_t}{TPF_{t-1}}) = \sum_{j=1}^{n} 0.5 \times (R_{j_t} + R_{j_{t-1}}) \times (\ln y_{jt} - \ln y_{j_{t-1}}) - \sum_{i=1}^{m} 0.5 \times (S_{i_t} + S_{i_{t-1}}) \times (\ln x_{it} - \ln x_{i_{t-1}})
\]

(1)

In the model above, \(t\) and \(t-1\) are adjacent time periods. There are \(n\) outputs and \(m\) inputs. Furthermore, \(y\) represents the output value, and \(x\) represents the input value. Also, \(R_j\) is the output weight, and \(S_i\) is the input weight. Furthermore, a certain output (or input) change is measured below:

\[
\ln(Output_{jt} / Output_{j_{t-1}}) = 0.5 \times (R_{jt} + R_{j_{t-1}}) \times (\ln y_{jt} - \ln y_{j_{t-1}})
\]

(2)

\[
\ln(Input_{it} / Input_{i_{t-1}}) = 0.5 \times (S_{it} + S_{i_{t-1}}) \times (\ln x_{it} - \ln x_{i_{t-1}})
\]

(3)

3. Inputs and Outputs

Drawn on the experience of oversea empirical studies and combined with the actual situation of China's power grid enterprises, the basic idea of input and output selection is put forward: starting from the "three responsibilities" of Chinese power grid enterprises (i.e. political responsibility, economic responsibility and social responsibility) [13], taking into account the measurability and operability of the input and output indicators, refining the core outputs of the grid business, analyzing the input-output correspondence relationship, and finally defining inputs and outputs in our study.

3.1. Outputs

Starting from the full connotation of the "three responsibilities", and taking into account the measurability and operability of the inputs and outputs, we define the core outputs of power grid business. Firstly, grid companies must ensure power supply and allow customers to "use power". Secondly, grid companies should provide good service and pursue comprehensive value, that is, make sure customers "enjoy good power". Finally, grid companies should "ensure the value preservation and appreciation of state-owned assets".

Therefore, we choose "line length" and "maximum load" to represent that grid companies connect users by transmission and distribution networks and meet their power demand, namely, allow customers to "use power".
"Minutes of power outages excluding external influences", which is a negative output, reflects that grid companies ensure customers "enjoy good power" by providing safe, high-quality, and reliable power supply services. The selection of "customer numbers" and "electricity sales" represents that grid companies "ensure the value preservation and appreciation of state-owned assets" to fulfill their economic responsibility.

3.2. Inputs
The outputs of power grid companies come from reasonable inputs. After the transmission and distribution price reform in China, the inputs of power grid companies need to be recovered with the permitted income approved by the regulators. If the inputs are not effective, they won’t be recovered from the permitted income. Permitted income is determined on the basis of assets and costs related to the provision of transmission and distribution services. Therefore, "the product of the capacity and length of transmission and distribution line", "transformer capacity", and "operation and maintenance fees" are selected to reflect the assets and costs related to the service provided in Figure 1. Related data of inputs and outputs mentioned above are collected from provincial grid companies.

![Figure 1. Inputs and outputs structure](image_url)

4. Weights of Inputs and Outputs
Section 3 explains the content of inputs and outputs and reasons for choosing these specific indicators. However, according to equation (1), we still need to work out the weights for those inputs and outputs, namely \( R_i \) and \( S_i \). Before that, price of inputs and outputs should be introduced.

4.1. Calculation of the Input Price
Operational input consists of operation and maintenance fees, which is even split into 3 categories according to their nature: material costs, labor costs and other costs. The input price for these three indicators is a price index used to eliminate price fluctuation. Referring to AER and EI’s idea [16], we select appropriate material price index \( q_1 \) and other cost price index \( q_2 \) and construct a wage price index \( q_3 \) separately. It should be noted that the three categories of operational inputs are then refined by eliminating their price fluctuation and become \( x_1, x_2, x_3 \) in equation (1, 2, 3).

As for a certain capital input \((x_i)\), the logic is different. We have to work out annual user’s cost for each capital input \((AUC_0)\) [16]. According to the transmission and distribution price regulation, annual user’s cost include regulatory depreciation, permitted income and in-price taxes. Then the price for each capital input \((q_i)\) can be worked out as:

\[
q_i = \frac{AUC_i}{x_i} \quad (4)
\]
4.2. Calculation of the Output Price

For the output of “minutes of power outages excluding external influences”, the price is designed as an estimation of the economic loss for each customer caused by the power outage.

\[ p_5 = \frac{y_1}{365.25 \times 24 \times 60} \times y_2 \times v_5 \]  

(5)

\( Y_1 \) represents electricity sales. \( y_2 \) represents customer numbers. And \( v_5 \) represents customer reliability value in RMB per kilowatt-hour, which indicates the value different types of customers place on having reliable electricity supplies under different conditions [17].

The other four positive outputs’ prices are determined by calculating the relationship between the value of a single input factor (dependent variable) and the value of the output factors, estimating the correlation coefficients, and then calculating the original weights. Coefficients are obtained by way of heuristic optimization algorithm. The original weights calculated with Matlab are shown in Table 1:

| Table 1. Original weights of the 4 outputs (h_j) |
|-----------------------------------------------|
| electricity sales | maximum load | customer numbers | line length |
| 28.88%            | 13.89%       | 34.01%           | 23.22%      |

Then, the final price for the four outputs is calculated as below:

\[ p_j = \frac{(Rev + y_5 \times p_5) \times h_j}{y_j} \]  

(6)

Among them, \( Rev \) indicates the transmission and distribution service revenue. \( P_5 \) is the price for “minutes of power outages excluding external influences”. \( Y_5 \) stands for “minutes of power outages excluding external influences”. \( H_j \) is the original weight of the \( j \)-th positive output factor, \( j = 1, ..., 4 \).

4.3. Calculation of the weights of inputs and outputs

With the values and prices of the inputs and outputs, the weights of the inputs (\( S_i \)) and the weights of the outputs (\( R_j \)) is then calculated as below:

\[ R_j (j = 1, ..., 5) = \frac{(p_j \times y_j)}{\sum_{i=1}^{5} (p_j \times y_j)} \]  

(7)

\[ S_i (i = 1, ..., 9) = \frac{(q_i \times x_i)}{\sum_{j=1}^{9} (q_i \times x_i)} \]  

(8)

\( P_j \) represents the price of the \( j \)-th output and \( y_j \) represents the value of the \( j \)-th output. \( Q_i \) represents the price of the \( i \)-th input and \( x_i \) represents the value of the \( i \)-th input.

5. Results

The overall TFP change of a certain power grid enterprise from 2008 to 2017 is shown in Figure 2. Its TFP remained basically stable for 10 years, as input and output growth were relatively similar. In 2010, while the investment has increased steadily, the electricity sales has increased by 39%, and the network reliability has also improved significantly, resulting in a slight increase in TFP in that year. However, in 2012, with the major transmission projects put into service, TFP gradually declined.
As shown in Figure 3, electricity sales have the biggest impact on the company's TFP improvement. In 2010, due to regional economic development, the electricity sales have increased significantly. Line length has continued to increase steadily, whose contribution to TFP remained stable. With the merge with the local power grids, the influence on TFP of customer numbers gradually exceeds that of maximum load. Network reliability has not improved significantly since 2008. Its index is always lower than the base value “1”, which has a direct and obvious negative impact on TFP.

Figure 4 depicts the input changes. Before 2016, the company's material costs had the greatest impact on TFP. But as the investment in 35-330kV lines increased, the influence of material costs on
TFP weakened. The changes of other costs and materials costs were in a reverse trend, indicating that there was a complementary relationship between this company’s operation and management. This company’s labor cost has remained low for a long time, and it had a greater contribution to the improvement of TFP than other power grid companies.

![Figure 4. Inputs of a certain power grid enterprise](image)

6. Conclusion
By comparing the TFP results of several provincial grid companies with the actual situation, we have verified TFP’s capability to reflect business reality. And the feasibility of TFP for measuring the efficiency of Chinese grid companies has been proven. As you can see, TFP is a complex result which is influenced by both inputs and outputs. Even though we break TFP change into detailed input and output change in this study, much work still need to be done to find out ways to improve TFP.

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