A Literature Review of the Empirical Research on TFP and Its Influencing Factors in Power Industry

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Abstract. Based on literature review, this paper studies the empirical research on total factor productivity (TFP) of power industry and its determinants. We found the TFP estimations were generally conducted on the industry level, less research on the micro firm level, and most studies were focused on growth factors including power reform, environmental constraints and technological progress. With insufficient decompose of firm TFP growth, it is difficult to provide practical advice for companies to increase their TFP.

1. Introduction

The power industry is closely related to the national energy security and national economy. As the backbone of the power industry, the state-owned enterprises (SOEs) are the main force to carry out the new development concept of the central government and promote the high quality development. State-owned Assets Supervision and Administration Commission (SASAC) puts forward the standard of building a world-class model enterprise with global competitiveness, and emphasizing that SOEs should provide high quality products and services with improved total factor productivity (TFP). But at present, the power industry and the SOEs have a relatively shallow understanding of the concept of TFP, and less practice of TFP evaluation. Therefore, this paper is aim to summarize and synthesize the existing empirical research on the TFP estimation in power industry, within China and abroad, and provide theoretical basis and research ideas for the TFP promotion of power enterprises.

2. Objects of TFP empirical research in power industry

The power industry includes four sub-sectors: generation, transmission, distribution and retail. Before the power reform in 2002, the power industry of China was managed by the integrated national power company. Hence, before 2002, the object of TFP estimation was mainly the whole sector of power industry [1, 2]. In order to study the influence of regulation reform on the power industry, some other scholars also regard the whole power industry as the research object [3, 4]. Some literature only focused on generation sector, and because of the characteristics of coal-based energy structure in China, most of domestic research focused on thermal power generation [5, 6, 7]. Generation sector has also been studied by foreign scholars. Kok Fong See [8] estimated thermal power TFP in Malaysia and Chiara F. Del Bo [9] measured the TFP of European power producers. Other scholars have carried out measures and...
interpretations on the TFP of power grid in China [10, 11]. Moreover, some scholars specializing in the TFP of distribution networks [12, 13, 14, 15].

No matter whether the research object is aimed at the whole power industry, the generation, the transmission, or the distribution, most of the above research scope is aimed at the whole macro industry, relatively few research is focused on the micro level of enterprises. Zheng Shilin and Wang Yunnan [10] selected the provincial power grid enterprise, which is integrated in transmission and distribution, as the research object, and studied the correlation between the growth rate of grid investment, the feed-in price and the selling price, the proportion of transmission and distribution price to the selling price and the technical efficiency, which has practical reference value for TFP promotion of power grid enterprises. Tovar [16] measured the TFP of 17 private distribution network companies in Brazil from 1998 to 2005 and concluded that enterprise size contributed to TFP growth.

3. Approaches to measure TFP of power sector

Practical research used methods including parametric, non-parametric and semi-parametric methods to estimate TFP of power sector. The most used parametric methods include Solow Residual [5] and Stochastic Frontier Analysis(SFA) [8, 16]. The nonparametric methods include Data Envelopment Analysis (DEA) [17, 12, 11] and index method, in which the index method is represented by Malmquist [18, 14, 11], Malmquist-Luenberger [7, 6, 4] and Törnqvist [3, 22]. The semi-parametric method is represented by Levinsohn-Petrin [10].

Solo residual is the very first measurement on TFP proposed by Solo [19]. Based on the assumption of neutral technical progress and constant return to scale, the D-C production function is used to deduct the input factor growth from the total output growth, and the remaining uninterpreted part is total factor productivity. This method is simple and easy to operate, but there can only be one output element in the calculation. Aigner et al. [20] proposed the stochastic production frontier analysis method, however, the basic assumption is more complex, it needs to consider the distribution form of production function and also the technical inefficiency term, thus, it’s easy to cause the problem of model setting and estimation bias. Nonparametric methods represented by DEA can solve such problems. The DEA methods proposed by Charnes. Cooper and Rhodes [21] are used to calculate the technical efficiency by linear programming model with multiple inputs and outputs, but the influence factors of TFP change cannot be directly analyzed by DEA method, further regression analysis is needed. Index method is a statistical method, which is obtained by the ratio of total output to total input in a period of time. When total factor productivity is measured solely by the index method, the Tornqvist index method is generally used, and the Malmquist index method is usually used with DEA or SFA for decomposing the TFP change.

4. Determinants of TFP change in power industry

4.1. Impact of power reform on TFP

Power regulation reform includes functional separation, market reform, privatization reform and other organizational changes. Function separation refers to the separation of power generation, transmission, distribution and retail sectors in the power industry. The power market reform introduces the power trading mechanism, accompanied by the change of the market supervision mechanism, while the privatization reform introduces the competition of the market and thus tries to improve the efficiency. A group of scholars have carried out the empirical research on the power reform in the world by measuring and decomposing the TFP growth of the power industry. According to the empirical research, domestic scholars generally believe that the power reform in 2002 played an important role in promoting the TFP of China’s power industry, while foreign scholars have different evaluation of the power reform in different regions.

In China, Bai Xuejie and Mao Wenjie measured the TFP changes of China’s power industry between 1993 and 2008, and analyzed the influencing factors of TFP through regression model [3]. The results showed that the regulation reform of China’s power industry in 2002 had a positive productivity improvement effect. Zheng Shilin and Wang Yannan [10] used the panel database of power grid
enterprises in China from 2000 to 2007 to calculate the TFP and growth rate during the period of power reform. On this basis, the changes of productivity of power grid enterprises before and after "separation of plant and grids" were compared. It is found that the productivity growth of most provincial power grid enterprises is remarkable during the power reform period. From the regional point of view, the productivity of power grid enterprises in the eastern region is obviously higher than that in the central and western regions, but the power reform in 2002 has become an important dividing point for the change of regional power grid productivity, and the productivity of the central and western and eastern power grids has begun to converge.

Aghdam [18] selected panel data from eight states in Australia from 1969 to 2007 to measure the power industry TFP, and used the hypothesis testing method to analyze the promotion effect of reform on the efficiency of the power industry. The results showed that functional unbundling and corporate public corporatisation played a major role in promoting the efficiency of the power industry, followed by market restructuring and privatization. See and Coelli [22] measured the TFP growth of the Malaysian Distribution Company from 1975 to 2005 and showed that the restructuring of the Malaysian industry in 1995, concluded the establishment of an independent power generation company, had not contributed to productivity gains, arguing that, despite the introduction of different producers in the market, only one company had finally acquired the electricity produced, and that the introduction of electricity trading mechanisms would have a driving effect on efficiency gains.

4.2. Impact of types of enterprise ownership on TFP
A number of scholars argue that the form of enterprise ownership have an impact on the TFP change of the power industry, while focuses of each study is slightly different. Ma Tian [5] measured the influence of the form of enterprise ownership on the power industry TFP, the regression results showed that the privatization process was beneficial to the improvement of the TFP. Study on the Australian electricity industry shows that public ownership plays a major role in TFP growth, followed by privatization [18]. And the empirical research on Europe generally believes that external institutional quality is the most important factor to affect the TFP growth of the power industry. Chiara F. Del Bo (2013) estimated and analyzed the TFP of power generation enterprises in 20 countries in Europe from 2002 to 2009, the results show that there is a clear correlation between the promotion of foreign investment introduction and the TFP, in addition, the quality of regional institutions is positively correlated with the TFP. This view was also confirmed by the Borghi et al's [15] decomposing of distribution companies TFP in 16 EU countries from 2002 to 2009, which found that public and private ownership were less relevant to TFP and that the decisive factor was the quality level of external government institutions.

4.3. Impact of technological change on TFP
Empirical studies show that technological progress is the main reason to improve total factor productivity in power industry, while the impact of technological efficiency on total factor productivity is limited. Sun Jianguo and Li Wenpu [16] made an empirical analysis of the technological efficiency and the changes of technological efficiency, technological progress and TFP change in the power industry between 1990 and 1997, using panel data from 18 countries. According to the results of the research, there are accelerating technological progress in the power industry, and the average technical efficiency level changes and TFP growth of the power industry in various countries, although different, but basically show a trend of growth. The study also shows that the competition-oriented regulatory reform in the 1990s promoted the technical efficiency level and TFP level of the power industry. The Ramos-Real et al [12] estimated and analyzed the TFP changes in Brazil’s distribution sector from 1998 to 2005, and concluded that promoting technological progress was the most important result of the reform, but which had a negative effect on technological efficiency. See and Coelli [8] measured the TFP of the Malaysian power generation sector in 1998-2005 and decomposed TFP growth as technological progress and changes in technological efficiency, and concluded that technological progress was the main factor contributing to TFP growth.
4.4. Impact of environmental constraints on TFP

Domestic scholars have made an empirical study on the impact of environmental regulation on the TFP of power industry, and concluded that environmental constraints will generally promote the TFP growth of power industry. Wang Juan and Zheng Haoyuan [4] calculated the power industry TFP considering environmental constraints in China’s 30 provinces from 2001 to 2012 using the Malmquist-Luenberger productivity index with SO2 emissions from the thermal power industry as the unexpected output, compared the differences of the power industry’s TFP with environmental constraints and without environmental constraints. The research found that the TFP of power industry considering environmental constraints is lower than the TFP without environmental constraints, and the “Porter effect” appears in the eastern region. Zhu Chengliang [7] included SO2 emissions as an unexpected output in the TFP measurement framework of thermal power industry, and used the Malmquist-Luenberger productivity index to measure and decompose the TFP of thermal power industry in 30 provinces in China. The results show that the "Porter hypothesis" exists in China's thermal power industry, and environmental regulation contributes to the thermal power TFP growth; the proportion of state-owned assets, standard coal consumption, coal price and the TFP are significantly negative correlated, power price and the TFP are significantly positive correlated.

5. Conclusion

By summarizing the existing studies, the findings are as follow: 1. The research on TFP of power industry is carried out from two levels: industry and enterprise; the research object include whole power industrial chain, generation, transmission and distribution sectors. 2. Existing empirical research methods mainly include Solo residual method, SFA method, DEA method and index method. 3. Researchers generally believe that functional separation in power reform promotes the TFP growth of power industry, but hold different views on the contribution of ownership form to TFP growth, and generally believe that external institution quality is the main influencing factor of power industry TFP growth. 4. Existing research generally believes that power sector reform has stimulated teleological progress and thus increased the TFP growth of the power industry. 5. Domestic research holds that there exists the Porter hypothesis in China's power generation sector, as environmental constraints help enterprises to improve their innovation vitality and thus enhance their profitability.

From the above study, it can be found that, at present, the most common TFP growth determinant analysis focused on power reform, environmental constraints and technological progress, and the TFP growth is generally analyzed from the power industry level, which provides a good reform reference for the government departments. However, for enterprises, the further explanation of technological progress is more important. At present, it is difficult to provide practical advice for enterprises to improve their TFP. Under the background that the country advocates the use of TFP as a measure of enterprise level, TFP research should focus more on the micro firm level, and provide scientific evidence for power firms to make better decision.

With the enact of No.9 reform document in 2015, China's power sector reform has reached a new historical stage. A number of new policies and measures, such as the construction of the power market, the pilot reform of mix shareholding on incremental distribution and the liberalization of the power generation plan, will accelerate the reform. The TFP of the power industry in China will also produce new changes, and the effectiveness of the new round of power reform measures will also become a focus of our future research.

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References

[1] Y. Yan, Regression Analysis of Total Factor Productivity in Power Enterprises, Journal of industrial technological economics. 04(2003) 83-84.86.

[2] Y. Wu, Estimation of Total Factor Productivity in Electric Power Industry - Research Based on Chinese Provincial Panel Data, Northern Economy. 017(2007) 52-53.

[3] X. Bai and J. Mao, Evaluation of Regulation Reform Effect of Total Factor Productivity Change in China's Power Industry, Journal of Hunan University of Science and Technology (Social Sciences Edition). 16.5(2013) 98-101.

[4] J. Wang and H. Zheng, Study on Total Factor Productivity in China Power Industry under Environmental Constraints - Panel Data Analysis Based on Malmquist-Luenberger Productivity Index, J Dongbei Univ Financ Econ. No.102.06(2015) 18-23.

[5] T. Ma, Analysis of Influencing Factors of Total Factor Productivity in China's Power Industry and Countermeasures of Structural Adjustment under the Financial Crisis, National PhD academic conference in 2009. Fujian, 2009, pp. 650-660.

[6] T. Zhao, T. Sun, and W. Guo, Environmental Efficiency and Total Factor Productivity of Thermal Power Enterprises, Financ Trad Res. 05(2015) 25-31.

[7] C. Zhu, Total Factor Productivity and Influence Factors of China's Thermal Power Industry under Environmental Regulations, Review of Economy and Management. 006(2016) 60-70.

[8] K.F. See, and T. Coelli, Estimating and decomposing productivity growth of the electricity generation industry in Malaysia: A stochastic frontier analysis, Energy policy. 62 (2013) 207-214.

[9] C.F. Del Bo, Productivity in electricity generation: The role of firm ownership and regional institutional quality, International Review of Applied Economics. 27.2 (2013) 237-264.

[10] S. Zheng and Y. Wang, An Assessment of the Productivity Change of China's Power Grid Enterprises during the Electricity System Reform Period, Journal of Graduate School of Chinese Academy of Social Sciences. 006(2015) 42-49.

[11] G. Zhang and D. Xia, Study on Technical Efficiency and Total Factor Productivity of Transmission and Distribution Grid, in China: Analysis Based on Panel Data of 24 Provincial Power Companies from 2005 to 2009, J Financ Econ. 038.010(2012) 112-122.

[12] F.J. Ramos-Real, et al, The evolution and main determinants of productivity in Brazilian electricity distribution 1998–2005: An empirical analysis, Energy Economics. 31.2 (2009) 298-305.

[13] B. Tovar, F.J. Ramos-Real, and E. F. Almeida, Firm size and productivity. Evidence from the electricity distribution industry in Brazil, Energy Policy. 39.2 (2011) 826-833.

[14] Y. Shen, Study of the input-output overall performance evaluation of electricity distribution based on DEA method, Energy Procedia. 16 (2012) 1517-1525.

[15] E. Borghi, C. Del Bo, and M. Florio, Institutions and firms' productivity: evidence from electricity distribution in the EU, Oxford Bulletin of Economics and Statistics. 78.2 (2016) 170-196.

[16] J. Sun and W. Li, International comparison of technological efficiency and total factor productivity growth of power sector, China economic problem 06(2003) 36-42.

[17] A. Estache, B. Tovar, and L. Trujillo, How efficient are African electricity companies? Evidence from the Southern African countries, Energy policy 36.6 (2008) 1969-1979.

[18] R.F. Aghdam, Dynamics of productivity change in the Australian electricity industry: Assessing the impacts of electricity reform, Energy Policy. 39.6 (2011) 3281-3295.

[19] R.M. Solow, Technical change and the aggregate production function, The review of Economics and Statistics. (1957) 312-320.

[20] D. Aigner, C.K. Lovell, and P. Schmidt, Formulation and estimation of stochastic frontier production function models, Journal of econometrics. 6.1 (1977) 21-37.

[21] C. Abraham, W. Cooper, and E. Rhodes, Measuring the efficiency of decision making units, European journal of operational research. 2.6 (1978) 429-444.

[22] F.K. See, and T. Coelli, Total factor productivity analysis of a single vertically integrated
electricity utility in Malaysia using a Törnqvist index method, Utilities Policy. 28 (2014) 62-72.

[23] Y. Yan, Empirical research of Total Factor Productivity in the Sustainable Development of Power Economy, Journal of industrial technological economics. 02(2003) 103-104.