Utilities Policy 31 (2014) 114–120

Contents lists available at ScienceDirect

Utilities Policy

journal homepage: www.elsevier.com/locate/jup

# Productivity change and its determinants: Application of the Malmquist index with bootstrapping in Iranian steam power plants

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ARTICLE INFO

*Article history:*
Received 8 June 2014
Received in revised form
6 October 2014
Accepted 7 October 2014
Available online 29 October 2014

*Keywords:*
Bootstrapping Malmquist index
Truncated regression
Steam power plants

ABSTRACT

In this paper, the bootstrapping Malmquist index is used to derive the productivity levels of Iranian steam power plants for the period of 2007–2012. The research shows that the average level of productivity has significantly decreased. It was also indicated that technological changes have had more effects on productivity than efficiency changes. To study the influence of various explanatory factors, the truncated regression method was used. The results show that factors such as liberalization of energy carrier prices, the ratio of the number of technicians to the total number of staff, and the age of power plants affect levels of productivity.



## 1. Introduction

Electric power generation is the most important and yet the costliest part of the electricity industry. Production of electricity in Iran is mainly connected to extracting fossil fuels and using non-renewable energies (Fallahi et al., 2011). According to Fig. 1, based on the statistics from The World Bank, annual per-capita electricity consumption in Iran is lower than the global average or the United States' consumption (http://data.worldbank.org). In 2012, the steam power plants have produced 40.8 percent of the total electricity supply of Iran. This places them in the first place of power supply (Annual operation statistics, Tavanir Company, www.tavanir.org.ir).

In the long run, improvement of efficiency of power generation will help to reduce the requirements of system capacity and energy costs (Fallahi et al., 2011). On the other hand, according to Iran's fifth development plan (2010–2015), all economic sectors are obliged to provide at least one-third of GDP growth from Total Factor Productivity (TFP).

Electric power plants need to apply systematic methods to measure their performance in order to maintain growth and profitability in a competitive environment. Assessment of productivity would lead to determination of the effective factors on performance and periodic qualification. By applying the results from the past data, one can identify and resolve the possible causes of problems. In general, the efficiency of electric power plants is defined as the amount of electricity produced per energy input. This ratio only takes the amount of heating value of the fuel into account, while other variables such as installed capacity and consumed electricity are ignored (Liu et al., 2010).

There are different methods for obtaining the TFP. One of the most important methods is the Malmquist index. Among the advantages of this index is its ability to be decomposed into different components. By applying this decomposition, the analysis and identification of the resources for growth in productivity can be performed more accurately.

Calculation of the Malmquist index requires an estimate of the distance function. The approaches to estimating distance function can be divided into parametric and non-parametric categories. Among the most important methods are the parametric method of Stochastic Frontier Analysis (SFA) (Lovell et al., 1994) and the non-parametric method of Data Envelopment Analysis (DEA) (Färe et al., 1994). The DEA has been widely used in the literature (Nakano and Managi, 2008; Vaninsky, 2006, Abbott, 2006). One of the benefits of DEA is the ability to model multi-input and multi-output technologies even in the absence of price data; it also does not require any kind of restrictions on the form of the production function regarding the inputs and outputs. On the other hand, its main drawback is failure to provide information about the estimate's

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http://dx.doi.org/10.1016/j.jup.2014.10.001
0957-1787/

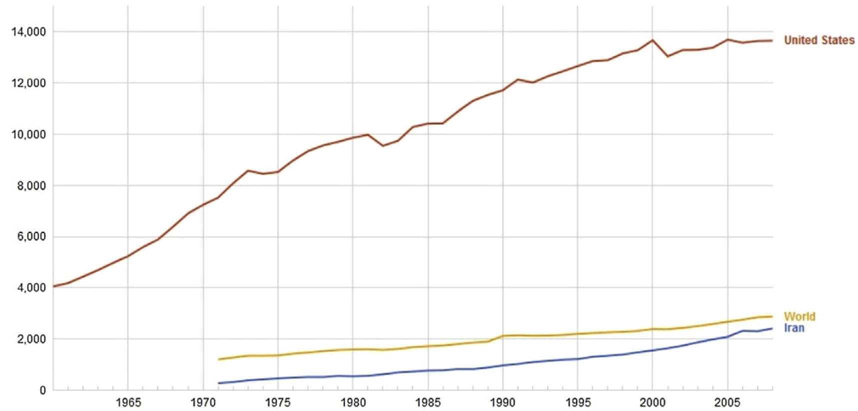


**Fig. 1.** Electricity consumption per capita (Data from World Bank).

uncertainty. In other words, we cannot determine whether or not there is a significant statistical difference between two or more estimates. Simar and Wilson (1998) solved this problem in DEA with the bootstrap method, which was originally suggested by Efron (1979). This method has been used in various sectors, such as agriculture, aviation, banking, and education (Odeck, 2009; Assaf, 2011; George Assaf et al., 2014; Parteka and Wolszczak-Derlacz, 2013).

In recent years, there has been a considerable amount of research focusing on the study of productivity and efficiency in the field of power generation and distribution by applying DEA method and Malmquist index, but few studies about sample variation and its role in obtaining productivity and identifying the effective factors simultaneously.

In this paper, the productivity and efficiency of all steam power plants in Iran during the period of 2007–2012 are assessed by applying the Malmquist method. The bootstrap method is then used to obtain the stability of extracted factors. Finally, the effects of explanatory factors (such as liberalization of energy prices, size, age and technology used in the construction of power plants) on changes in efficiency, technology, and TFP are analyzed by the truncated regression model. According to the literature, construction technology and liberalization of energy prices are two new topics in the study of factors affecting performance.

This paper is organized as follows: in section 2, the previous literature is briefly reviewed and discussed. In section 3, the applied methodology is described. The empirical analysis results are presented in section 4 and section 5 concludes the study.

## 2. Literature review

Several studies have been conducted on the performance of the electricity industry in the world heretofore. In this section, the recent literature on implementation of Malmquist index and data envelopment analysis (DEA) in the study of productivity and efficiency of electricity industry are reviewed and discussed.

Singh et al. (2013) studied the changes in productivity of 25 state-owned coal-fired power plants in India during 2003–2010 by applying the Malmquist index based on DEA. The results showed that the average TFP declined in the studied period by an annual rate of 2 percent. The results also indicate that there are little differences in the level of productivity in small power plants compared to medium or large ones.

Fallahi et al. (2011) studied changes in productivity of 32 electricity production management companies in Iran from 2005 to 2009. The results showed that changes in productivity growth were slow during the aforementioned period and this slowness has been only due to the small changes in efficiency. In addition, the results indicated positive changes in technology in all of the companies except one.

In another article, Wu et al. (2010) studied the efficiency and productivity of 30 coal-fired power plants in China. The results showed that TFP growth has been linked to changes in technology. This research also showed that the eastern provinces had more efficiency and productivity among the studied areas.

Liu et al. (2010) evaluated the efficiency of thermal power plants in Taiwan from 2004 to 2006 by applying a DEA approach. According to their results, all of the evaluated power plants reached an acceptable operational efficiency during the studied period. In addition, the combined cycle power plants were the most efficient types. The main variable in the DEA model of this study was heating value of total fuels.

Nakano and Managi (2008) measured the productivity of steam power generation sector in Japan and also studied the impact of reforms on productivity over the period 1978–2003. The results indicated that regulatory reforms have contributed to productivity growth.

Barros (2008) studied the efficiency of hydroelectric generating plants using a two-step procedure. First, the Malmquist index based on DEA was used to identify the values of efficiency and productivity for each unit. At the second step, the effect of environmental variables was identified using regression analysis. The results indicated that hydroelectric power plants have shown an average improvement in technology and efficiency.

Barros and Peypoch (2008) analyzed the technical efficiency of thermoelectric power generation plants applying a two-step process. At first, the plants' relative technical efficiency was estimated using DEA. At the second step, the efficiency drivers were estimated through a bootstrapped procedure. The results showed that the majority of thermoelectric energy plants do not operate in an efficient frontier.

Sarica and Or (2007) analyzed and compared the efficiency of electric power plants in Turkey. They showed that coal-fired power plants have less efficiency than natural gas-fired power plants. The operational performance efficiency of public thermal power plants has been significantly lower than their private counterparts.

Wang et al. (2007) analyzed the efficiency of electric power supply industry of Hong Kong and its impacts on prices by applying a price-cap performance-based regulation (PBR) model. The DEA method was used to calculate TFP with the Malmquist productivity index (MPI). The results support using this approach to account for the relation between X-factor and the PBR model on two power utilities.