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# A Bayesian stochastic frontier analysis of Chinese fossil-fuel electricity generation companies

Zhongfei Chen [a,*], Carlos Pestana Barros [b], Maria Rosa Borges [b]

[a] Lingnan College, Sun Yat-Sen University, No.135 Xingang West Road, Guangzhou, Guangdong Province, China
[b] Instituto Superior de Economia e Gestão, University of Lisbon, Rua Miguel Lupi, 20, 1249-078 Lisbon, Portugal

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ABSTRACT

This paper analyses the technical efficiency of Chinese fossil-fuel electricity generation companies from 1999 to 2011, using a Bayesian stochastic frontier model. The results reveal that efficiency varies among the fossil-fuel electricity generation companies that were analysed. We also focus on the factors of size, location, government ownership and mixed sources of electricity generation for the fossil-fuel electricity generation companies, and also examine their effects on the efficiency of these companies. Policy implications are derived.



## 1. Introduction

With the onset of reform and the "Open-door" policy that has been in place since 1978, China's economy began to prosper with impressive growth over the following decades. A boom in electric power industry in China was witnessed to cater for the tremendous demand for power (Shiu and Lam, 2004; Yeoh and Rajaraman, 2004). The installed electricity capacity leapt from 65.87 million kilowatts in 1980 to 1100.49 million kilowatts in 2011, whilst total net electricity generation soared from 285.47 billion kilowatt hours to 4490.54 billion kilowatt hours during the same period. China has now become the largest electricity consuming country in the world, since 2011.

The main cause of this impressive growth was the reform of the power sector, which was launched in three main stages by government authorities over the last three decades. Before the reform, Chinese electricity generation plants were vertically integrated as state-owned utilities, in the form of an absolute monopoly. The administration, investment and price levels were completely controlled by the central government (Wang and Chen, 2012). Since 1985, the government gradually introduced three waves of reform to deregulate the power industry in China and established modern electricity generation companies. However, there are still some operational distortions that have not been corrected. Firstly, the monopolistic situation has still not been significantly dismantled and the Big Five[2] control the majority share of electricity generation, which causes a loss of welfare (Wang and Chen, 2012). Secondly, the price of electricity is inflexible, given the government's regulation and inflation concerns, whilst the price of coal is determined by the open market. The booming economy and expansion of the manufacturing sector have pushed up the price of coal, as well as the cost to these companies, which takes them to the brink of bankruptcy, although the government has formulated a plan to supply coal at a lower price in order to subsidise fossil-fuel electricity generation companies.

Compared to other sources, including hydroelectric power, nuclear power, wind power, solar power, and bio-energy, fossil-fuel power plays the most important role and provides the majority of China's

* Corresponding author. Tel.: +86 15913197920.
*E-mail addresses:* hongyeczf@163.com (Z. Chen), cbarros@iseg.utl.pt (C.P. Barros), mrborges@iseg.utl.pt (M.R. Borges).

[2] i.e., China Huaneng Group, China Guodian Corporation, China Datang Corporation, China Huadian Corporation and China Power Investment Corporation. They are all big state-owned electricity generation companies.

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electricity.[3] The clean energy sources, i.e., nuclear and other non-hydroelectric renewable energies, were not developed greatly, until recent years.

Motivated by the important status of fossil-fuel power and the series of complicated reforms that electricity generation companies in China have undergone (Zhou et al., 2010a, 2010b; Du et al., 2013; Elliott et al., 2013), this paper examines the technical efficiency of a sample of Chinese fossil-fuel electricity generation companies which produce electricity with coal turbines, gas turbines or diesel turbines. Meanwhile, monitoring the efficiency performance of Chinese fossil-fuel electricity generation companies can provide useful information for assessing the effectiveness of energy efficiency policies and measures, as a means of improving energy efficiency and productivity, and also as a way to achieve sustainable development in the most cost-effective way (Ang, 2006; Ang et al., 2010; Wang et al., 2013). Furthermore, restrictions of energy sources and environmental protection have boosted the development of renewable energy sources to produce clean energy, in line with the Kyoto protocol (Gorecki et al., 2010). The Eleventh Five-Year Plan of the Chinese central government sets the target to control energy consumption and promotes low-carbon development (Wang et al., 2013). This competition is also forcing the Chinese fossil-fuel electricity generation companies to upgrade their efficiency when competing for market share (Barros and Peypoch, 2008).

Several methods have been widely adopted to measure the efficiency of electricity generation companies and plants (Barros and Peypoch, 2007; Barros, 2008; Ang et al., 2010; Briec et al., 2011; See and Coelli, 2012), including data envelop analysis (DEA) models (Barros, 2008; Briec et al., 2011; Sueyoshi and Goto, 2011) and stochastic frontier analysis (SFA) models (Aigner et al., 1977; Barros and Peypoch, 2007; Huang et al., 2010; Growitsch et al., 2012; See and Coelli, 2012), blended DEA and stochastic frontier models (Jaraitė and Di Maria, 2012) and recently the StoNED—stochastic Non-Smooth Envelopment of Data (Kuosmanen, 2012; Mekaroonreung and Johnson, 2012; Saastamoinen and Kuosmanen, in press). This paper adopted the Bayesian stochastic frontier model to estimate the efficiency of Chinese fossil-fuel electricity generation companies for the first time. The Bayesian stochastic frontier model (Orea and Kumbhakar, 2004; Greene, 2005) has an advantage, in that the technique incorporates informative priors, so that prior knowledge, or results of a previous model, can be used to inform the current model. Furthermore, small sample inference is carried out in the same way as if one had access to a large sample, and all inferences follow logically from Bayes' theorem. Therefore, any sample size can be accommodated, no matter how small. The estimation is unbiased with respect to sample size. This is in contrast to frequentist inference, which becomes more biased as the sample size decreases from infinity. In addition, it obeys the likelihood principle. Bayesian inference is consistent with much of the philosophy of science regarding epistemology, where knowledge cannot be built entirely through experimentation, but requires prior knowledge (Koop et al., 1997; Griffin and Steel, 2007).

A cost function is adopted and the translog form is used, which is flexible and leads to a robust cost efficiency measure (O'Donnell and Coelli, 2005). The main issue in efficiency analysis is the choice benchmark by which fossil-fuel electricity generation companies can be analysed.

The rest of this paper is organised as follows. After this introduction, the literature survey is presented, followed by research hypotheses. Then the methodology is outlined, followed by the data, results and robustness tests. The final sections present the conclusions.

[3] According to the statistics of EIA (U.S. Energy Information Administration), electricity produced by fossil-fuel electricity generation companies accounts for 79.58% of total electricity generation on average during the period from 1980 to 2011.

## 2. Literature survey

We divide this section into two parts. Firstly, we review other widely-used methods for estimating the efficiency of electricity generation companies and plants, in order to further justify the choice of the Bayesian stochastic frontier model in this paper. Secondly, we summarise the literature on the Chinese power sector, and highlight the significance of this present research.

### 2.1. Review of alternative methods

There are many alternative approaches for estimating the efficiency of electricity generation companies and plants, such as: the SFA—stochastic frontier analysis (Hattori, 2002; Farsi and Filippini, 2004; Barros and Managi, 2009; Barros and Peypoch, 2007, 2008; Barros and Antunes, 2011; Kopsakangas-Savolainen and Svento, 2011; See and Coelli, 2012); the DEA—data envelopment analysis (Nakano and Managi, 2008; Arocena, 2008; Zhou and Ang, 2008) and StoNED—stochastic Non-Smooth Envelopment of Data (Kuosmanen, 2012; Mekaroonreung and Johnson, 2012; Kuosmanen et al., 2013; Saastamoinen and Kuosmanen, in press). However, classic data envelop analysis (DEA) and stochastic frontier analysis (SFA) assume that all the analysed units operate under the same production or cost technology for the estimation of efficiency. Tsionas (2002) argues that these methods have limitations which may lead to incorrect efficiency estimates and thus it is inappropriate to use them in isolation. The Bayesian SF model caters for heterogeneity, and is closer to reality, thus ensuring that efficiency is correctly estimated. The new StoNED method proposes a two-step estimator which combines the axiomatic DEA-style non-parametric frontier with the probabilistic SFA-style treatment of noise, and does not make any assumptions about the functional form, neither its smoothness (Kuosmanen and Kortelainen, 2012; Dai and Kuosmanen, 2014). However, StoNED still has its own limitations, which highlights the need for further investigation of the underlying axiomatic foundation, statistical properties and performance of the technique, as it is very restrictive (Lin et al., 2013; Simar et al., 2013; Martins-Filho and Yao, 2015).

### 2.2. Research on the Chinese power sector

The analysis of energy efficiency in power generation is a well-established field of research (Knittel, 2002; Farsi and Filippini, 2004, Managi et al., 2006; Vaninsky, 2006), which enables significant insight into the performance of power plants and their potential for increasing productivity and for improving resource-use (See and Coelli, 2012). However, rarely has research paid attention to the Chinese power sector.

Up until recent years, a growing strand of literature began to focus on energy efficiency in China. In the early stage, some authors only researched and introduced the background and the situation of the power sector of China (Yang and Yu, 1996; Shiu and Lam, 2004; Xu and Chen, 2006; Ma and He, 2008; Chai et al., 2009). Later on, academics placed more emphasis on energy efficiency. Lam and Shiu (2001, 2004), Hu and Wang (2006), Wei et al. (2009) and Shi et al. (2010) apply the DEA as a means of analysing the technical efficiency of fossil-fuel electricity generation, with province-level data from China. Wu et al. (2012), Zhou et al. (2012a, 2014), Wang et al. (2013) and Bi et al. (2014) all further consider the undesirable output or environmental constraints when evaluating the efficiency performance in China's fossil-fuel power sector; and Choi et al. (2012) further improve the above-mentioned research with replacing the radial DEA for a non-radial slack-based DEA. Yang and Pollitt (2009) estimate the efficiency of the Chinese coal-fired power plants with DEA, incorporating both undesirable outputs and uncontrollable variables; and Du et al. (2013) assess the TFP of Chinese fossil-fired power plants following traditional SFA and conclude that the reform in the power sector had improved the efficiency. These studies reflect the dynamics of the efficiency of