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Measuring unified efficiency of Chinese fossil fuel power plants: Intermediate approach combined with group heterogeneity and window analysis

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ABSTRACT

As a newly-proposed method, intermediate approach has several unique features, relative to conventional radial and non-radial approaches. This study contributes to the DEA literature by combining intermediate approach with group heterogeneity in a time horizon. This extended methodology has two important advantages, since it can separate inefficiency related to different production frontiers originated from heterogeneity issue and provide steady results of time effects across periods. Empirically, this method is used to examine unified efficiency of Chinese fossil fuel power plants at provincial levels from 2005 to 2015. All provinces are classified into two regional groups. Our main findings are as follows. First, there exists significant group heterogeneity between coastal and inland provinces, where coastal provinces outperform inland provinces. Second, there are considerable differences in unified efficiency measures across provinces. For most observations, best-practice gap ratio is the most important driving factor. Furthermore, the relative importance of three decomposed indicators varies sharply across provinces. Finally, the concept of managerial disposability should attract sufficient attention, when designing environmental policies. Thus, there should be more combined contributions from eco-technology advancements along with managerial efficiency improvements by corporate leaders and policy makers. This can a new direction for China's environmental policy.

1. Introduction

China's power sector has attracted wide policy attention, because of its large contribution to energy consumption and CO_2 emissions. During the past few years, China's electricity generation grew rapidly in order to support rapid economic growth. According to BP (2018), China's electricity generation reached 6142.5 TWh in 2016, which was 4.53 times of that in 2000. Meanwhile, there have been rapid increases in the share of China's electricity generation relative to the world total. In 2016, this share increased from 8.74% in 2000 to 24.75% in 2016. However, due to coal-dominated energy consumption mix, most of China's electricity has been generated from fossil fuels (particularly coal). According to Wind Database (2018), in 2015, 73.68% of electricity was generated from fossil fuels. As a result, power generation became an important source of China's CO_2 emissions. In 2014, 48.15% of China's CO_2 emissions (i.e. 13.62% of the world's total emissions) was attributed to power generation (IEA, 2017). Under such background, keen interest has been expressed by the researchers, academics and policymakers, concerning how to promote unified efficiency in China's power sectors (especially for fossil fuel power plants).

To prepare for environmental policy suggestions, it is important to make balances between sector prosperity and environmental protection. There has been one common worry about environmental policies, since these policies tend to go at the cost of sector prosperity (Yao et al., 2015; Li et al., 2015, 2017a, 2017b; Zhang et al., 2017). However, such worry may not be definitely true. For this reason, this study adopts the concepts of natural and managerial disposability, following Sueyoshi and Goto (2013a, 2013b, 2015, 2018). These concepts unify desirable and undesirable outputs in a framework. In this framework, this study can evaluate sector prosperity and environmental protection at the same time, where sector prosperity is measured by the level of desirable outputs and environmental protection is calculated by the amount of undesirable outputs (Sueyoshi and Yuan, 2015, 2016, 2017). In this way, this study assesses unified efficiency (operational and

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environmental efficiency) on Chinese fossil fuel power plants.

To measure unified efficiency, this study makes methodological extensions to the intermediate approach. Intermediate approach is a newly-proposed approach by Sueyoshi and Yuan (2017). As argued by Sueyoshi et al. (2017a), this new approach has several unique features, as compared with the two traditional approaches (i.e. radial and non-radial approaches). To contribute to the DEA studies, this study combines intermediate approach with group heterogeneity and DEA window analysis in a time horizon. The extended approach can deal with heterogeneity issue in a time horizon. Thus, it can measure inefficiency changes across periods related to different production frontiers caused by heterogeneity issue. To the best of our knowledge, this type of research cannot be found in the previous studies.

To design environmental policies, it is important to incorporate group (regional) heterogeneity issue in China. China is a transitional and developing economy and there have been considerable regional disparities. As argued by Battese et al. (2004), the obtained efficiency scores may be biased, when ignoring the heterogeneity issue. To address the issue, this study adopts the concepts of meta and group frontiers. This method classifies all observations into several groups with distinctive features, thus creating different types of frontiers. This method has been frequently adopted by the previous research, e.g. Wang et al. (2013), Yao et al. (2015), Munisamy and Arabi (2015), Li and Lin (2017b) and Li et al. (2018).

This study has three research tasks. First, this study investigates whether there is group heterogeneity in unified efficiency measures of fossil fuel power plants between coastal and inland provinces. Second, this study examines what are the driving factors affecting unified efficiency changes across periods. Finally, equipped with the concepts of natural and managerial disposability, this study discusses the policy directions for improving unified efficiency of Chinese fossil fuel power plants.

To carry out the above tasks, this study makes methodological contributions by combining intermediate approach with group heterogeneity in a time horizon. This new approach has two important methodological advantages. (1) This approach can assess inefficiency changes across periods originated from the heterogeneity issue. By adopting this approach, this study can separate the inefficiency scores originated from different frontiers (i.e. group or meta frontiers). Furthermore, unified efficiency scores can be decomposed into three components, with the purpose of identifying the underlying driving factors. (2) This approach incorporates DEA window analysis and thus has the advantage of providing more steady and credible results regarding time effects. To the best of our knowledge, this kind of research work has never been investigated by the previous research.

The remaining of this study is organized as follows: Section 2 provides the literature review. Section 3 introduces the method and the data. Section 4 analyzes the empirical results. Section 5 makes the concluding remarks.

2. Literature review

This study combines intermediate approaches with group heterogeneity, window analysis and two disposability concepts (i.e. natural and managerial disposability) in a time horizon. Empirically, the extended approach has been applied to assess the performance of Chinese fossil fuel power plants. In such a setting, there are three groups of studies which are highly related to this study.

The first group of studies was about the DEA studies, especially those on DEA environmental assessment. DEA was initially put forward by Charnes and Cooper (1978). Until now, DEA has gained great academic reputation in the research filed of performance assessment. Some of recent contributions in energy and environmental assessment can be found in Zhang et al. (2014), Yao et al. (2015), Sueyoshi et al. (2017a), (2018), Li et al. (2017a), (2017b), (2018), Tapia et al. (2017), Liu et al. (2017), Li and Lin (2015, 2016, 2017a, 2017b), Bi et al. (2018) and Zhang et al. (2018). Recent literature survey can be found in Sueyoshi and Goto (2018).

Particularly, this study was highly related to the DEA studies on intermediate approach. There were two categories of conventional DEA approaches (i.e. radial and non-radial approaches). Recently, a new category (i.e. intermediate approach) has been put forward by Sueyoshi and Yuan (2017). Sueyoshi et al. (2017a) and Sueyoshi et al. (2017a), (2018) made methodological comparisons among these three approaches and found that intermediate approach had several important features. Zhang et al. (2018) combined intermediate approach with DEA window analysis.

Importantly to note that intermediate approach had several unique features, as compared with conventional approaches (i.e. radial and non-radial approaches). In terms of efficiency measures, radial models have the “Debreu–Farrell measures”, while non-radial models have the “Pareto–Koopmans measure”. Differently, intermediate models determine unified inefficiency scores by measuring the average of the inefficiency scores on every production factor and thus belong to an intermediate case between “Debreu–Farrell measures” and “Pareto–Koopmans measure”. Concerning the objective functions, the intermediate approach maximizes both the sum of inefficiency score linked with every component of outputs and the sum of the slacks related to all production factors. Another important feature relies on the unification process between desirable and undesirable outputs, since the intermediate model separates the inefficiency scores corresponding to every component of desirable and undesirable outputs. For detailed discussion, readers can turn to Sueyoshi et al. (2017a).

The second group of studies is about DEA window analysis. DEA window analysis originated from Bowlin (1987). Thereafter, some studies followed this line of research, e.g. Thore et al. (1994) and Goto and Tsutsui (1998). As argued by Sueyoshi and Aoki (2001), DEA window analysis pooled adjacent observations into a window and thus created new efficiency frontiers. In such a setting, there could exist frontier shifts across periods. Furthermore, the newly-established efficiency frontiers were based on the observations with several adjacent periods. Due to the enlarged observations, the obtained efficiency scores were smoothed over time. Readers can turn to Sueyoshi and Aoki (2001) for a detailed discussion. Some recent studies of DEA window analysis can be found in Sueyoshi and Goto (2013b), Yang et al. (2016), Vlontzos and Pardalos (2017), Sueyoshi et al. (2017b) and Zhang et al. (2018).

The third (final) group of studies is about DEA environmental assessment on power plants. Table 1 lists the recent 20 studies on power plants. Table 1 provides us with the following four interesting concerns. First, among 20 studies, there were 8 studies on China. Thus, China was an important research focus. Second, there were 17 studies at power plant levels and 3 studies at industry levels. Hence, efficiency assessment at plant levels was an important research focus. Third, 18 studies incorporated undesirable outputs, implying that environmental assessment was an important research focus. In this regard, there were 12 studies on CO_2 and 11 studies on SO_2. Thus, these two pollutants were the research focus. Finally, there were 9 studies considering heterogeneity issue. All of these studies adopted the method of group heterogeneity, meaning that all observations were classified into several distinctive groups.

2.1. Position of this study

This study fully acknowledges the contributions of the existing studies. Based on the extant studies, this paper makes methodological extensions by combining intermediate approach with group heterogeneity in a time horizon. This new approach has the two important methodological advantages, as summarized at the end of Section 1. To the best of our knowledge, this kind of research has never been explored by the existing studies.

As an empirical application, the above approach is used to examine