ENVIRONMENTAL EFFICIENCY, TECHNOLOGY GAP AND SHADOW PRICE OF COAL-FUELLED POWER PLANTS IN CHINA: A PARAMETRIC META-FRONTIER ANALYSIS

China has become one of the main greenhouse gas emitters in the world because of its rapid economic growth and accompanying growth in energy consumption. In terms of its contribution to total emissions, the power sector is a major pollution source. According to statistics, CO2 emissions from electricity and heat production account for almost 50 percent of total emissions from combustion in 2011 in China (IEA, 2013). Though clean energy, such as hydropower, wind and solar power, has developed rapidly during the past decade, thermal power (especially coal-fuelled power) remains at present China's dominant form of energy generation(Xie et al., 2012). Thus it is extremely important to investigate the environmental efficiency, the marginal abatement cost and the abatement potential of China's power sector.

The importance of the power sector in environment protection has long been emphasized by previous studies. Multi-input/multi-output production theory combined with the directional (or Shephard) output distance function method is widely used to estimate the environmental efficiency and the marginal abatement cost for power plants. In spite of its widespread acceptance, one weakness of this method is that it does not consider plant heterogeneity while it assumes that plants share a common production frontier. Actually, the production sets of different firms may differ due to differences in physical, human and financial capital stocks, economic infrastructure, resource endowments and any other characteristics of the physical, social and economic environment in which production takes place (O'Donnell et al., 2008). If these differences are neglected, results from any estimation may be biased.

One possible way to consider plant heterogeneity is to implement a meta-frontier analysis. The typical procedure for this type of analysis is to proceed in two steps. The first step is to classify the plants into different groups according to their characteristics (such as region, ownership, industry, etc.) and to estimate the group-specific production frontier for each group respectively. The second step is to estimate the meta-frontier - i.e. the envelope of the group-specific frontiers (Battese et al., 2004; Chiu et al., 2012; Oh, 2010). Only very few studies have considered group heterogeneity in an analysis of the power sector, such as Zhang et al. (2013) and Zhang and Choi (2013). However, there still have rooms for improvement.

In this paper, we intend to propose a new meta-frontier estimation method, and then apply this newly proposed method to estimate the environmental efficiency and marginal abatement cost of CO2 emissions for China's coal-fuelled power plants. Our paper makes two key contributions. First, almost all the previous studies estimating environmental meta-frontier efficiency are based on the non-parametric Data Envelopment Analysis (DEA) approach, while our approach is based on parametric linear programming. The merit of our approach is that the estimated parametric directional output distance

functions are differentiable, thus allowing us to estimate the marginal CO2 abatement cost of the plants. Second, our empirical analysis covers a wider range of China's power plants than in previous studies.

The paper is organized as follows: Section 2 presents the methodology. Section 3 describes the data and variables. Section 4 reports the basic estimation results. Section 5 contains the sensitivity analysis. We conclude in the final section.