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Technology choice for reducing NO_x emissions: An empirical study of Chinese power plants

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ABSTRACT

This study investigates the choices of denitration technology in the Chinese thermal power sector. Using a multinomial logit model of the choices among 1135 boilers in thermal power plants operating in China in 2013, we analyze how the choices were influenced by government policies, the stringency of national standards, and subsidies for using specific technology. The results are as follows. First, China's 12th Five-year Plan might make it more attractive for plants to choose the cheapest denitration technology among the three options examined in this study. Second, technology choices differed significantly by region before the 12th Five-year Plan period. These differences have disappeared, perhaps due to the economic development across all regions of China. Third, electricity price subsidies offered to plants that use denitration equipment might affect their technology choice. These results suggests that plants might choose the cheapest technology available, in order to lower investment costs.

1. Introduction

A large proportion of air pollution in China stems from coal combustion: coal was the source of 90% of all sulfur dioxide (SO_2) emissions and 67% of nitrogen oxides (NO_x) emissions in 2005 (Liang et al., 2011). Although total SO_2 emissions from the industrial sector decreased from 22.37 million tons in 2006 to 18.35 million tons in 2013, total NO_x emissions increased from 11.36 million tons to 15.45 million tons during the same period (China State Statistical Bureau, 2007, 2014). NO_x emissions contribute to the formation of fine particles (PM10/PM2.5) that inflict significant damage to the health of Chinese citizens (Chen et al., 2015).

The regulation of NO_x emissions in China has lagged behind that of SO_2 emissions. Between 2005 and 2010, the share of thermal power plants that installed desulfurization equipment increased from 14–86%. As a result, total SO_2 emissions decreased 14.29% during the same period. In contrast, the Chinese government shifted its focus to the regulation of NO_x, starting with the 12th Five-year Plan initiated in 2011. This plan announced, for the first time, a concrete target for reducing nitrogen oxide emissions: a 10% reduction in NO_x emissions from the 2010 levels by 2015 (State Council of the People's Republic of China, 2011a).

Several policies were implemented to control NO_x emissions during the 12th Five-year Plan (2011–2015). The 12th Five-year Plan on Environmental Protection insists that all newly built power generation units and existing units whose capacities exceed 300 MW be coupled with denitration equipment (State Council of the People's Republic of China, 2011a). The new NO_x emission standards were released in July 2011 and took effect in January 2012. Furthermore, the government issued the 12th Five-year Plan for the Prevention and Control of Air Pollution in Key Regions (Key Regions Plan) in October 2012 (Chinese Ministry of Environmental Protection, 2012). It sets higher emissions reduction targets in specific regions designated according to the type and level of air pollutants experienced there. The government also offered subsidies to thermal power plants that used denitration equipment. As a result, the use of technology for controlling NO_x began to proliferate. As of 2013, 1238 pieces of denitration equipment had been installed on 7515 boilers in 3102 power plants in China.[1] By 2013, NO_x emissions from the thermal power sector had decreased 1.2 million tons (or by 11%) from the 2012 volume (Chinese Ministry of Environmental Protection, 2014a).

Several engineering studies have investigated the role of technological options for controlling NO_x emissions in the thermal power sector in China. Xiong et al. (2016) investigated the emission inventory of

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[1] The number is the total of utility power plants and non-utility power plants. The latter consists of power plants managed by industrial sectors for their own energy consumption. There were 1853 utility power plants and 1249 non-utility power plants in China in 2013. They have 4825 and 2690 boilers, respectively. Among them, 1076 utility boilers and 162 non-utility boilers had installed denitration equipment in 2013.

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coal-fired power plants in Shandong and projected future emissions under three scenarios. Under the assumption that the penetration of selective catalytic reduction (SCR) and selective non-catalytic reduction (SNCR) technology would increase from 10% and 2% in 2012 to 95% and 5% in 2030, respectively, they predict that NO_x emissions will decrease by 80.63% relative to the 2012 baseline. Zhao et al. (2008) evaluate the cost-effectiveness of various coal-power technologies and estimate the differences in capital costs and overall cost of electricity. The net plant efficiency for the integrated gasification combined cycle (IGCC) technology is 45%, and NO_x emissions are minimized by using IGCC among all the technological options. However, the cost per unit of electricity generated while using IGCC is 30–40% higher than the option using SNCR technology, even when charges related to pollutant emissions are included. While these studies suggest that the technology adoption will play a key role in reducing NO_x emissions in China, details on the actual adoption process and its driving force have not been analyzed.

On the other hand, economic studies of the technology choices for controlling NO_x have focused on cases in developed countries. For example, Popp (2010) investigates links between knowledge stock and the adoption of NO_x control technology in US coal-fired power plants. His results suggest that an increased level of knowledge stock– measured by patent count– increases the adoption rates of combustion modification techniques and post-combustion treatments. Examining the impact of Swedish emission regulations, Sterner and Turnheim (2009) considered the process of technological change in relation to NO_x abatement from large stationary sources. They regressed the plant emission intensities of NO_x on various explanatory variables, including specific technological options. Their results suggest that the most significant and sizeable reduction was attained by using SCR, followed by that attained using SNCR. Bonilla et al. (2015) studied how the use of various NO_x abatement technologies has diffused under the Swedish system of refunded emission payments by analyzing the determinants of the time to adoption. Their results revealed an economy of scale: the greater the capacity of the boiler, the more likely it is that post-combustion technologies will be adopted. Their results also suggest that stringent standards increase the regulatory costs of NO_x emissions and motivate firms to invest in more than one NO_x-reducing technology. They attribute no explanatory power to the predicted decrease in net charge liabilities or to most of the other covariates across the subsamples in Sweden.

This study focuses on the choices of NO_x control technology in the thermal power sector in China, where air pollution is a major issue under conditions of rapid economic growth. We analyze how technological choices have been influenced by government policies, the stringency of national standards, and subsidies for using specific technologies. We focus on the available post-combustion technologies, as the removal efficiency of NO_x through post-combustion technology is higher than that through the pre-combustion or combustion process. We find that SNCR adoption increased after 2010 and identify a clear distinction in regional distribution between the pre- and post- 2010 periods concerning the adoption of SCR technology. We also investigate how subsidies for operating denitration equipment affected SCR adoption and find that subsidies somewhat discouraged it, perhaps because SCR is more expensive than the other technological options.

In Section 2, we provide background information and develop our hypothesis. We also introduce the denitration technology, national standards, and various policies relevant to the NO_x emitted by thermal power sector in China. Section 3 explains the study's empirical strategy and data. Section 4 presents the study's empirical results, and Section 5 concludes the paper.

2. Background, and hypothesis development

2.1. Technological options for post-combustion control

The abatement of NO_x emissions occurs by way of three different processes: pre-combustion control, combustion modification, and post-combustion capture (Skalska et al., 2010; Cheng and Bi, 2014). Pre-combustion control involves fuel purification, used to reduce the nitrogen content of the fuel. Combustion modification refers to technology improvements in the boiler design, which can reduce NO_x formation during the combustion processes. Post-combustion technologies are end-of-pipe solutions that reduce NO_x in the flue gases following the combustion stage. Post-combustion technologies can remove up to 90% of NO_x (Guo et al., 2012), while that of pre-combustion control and combustion modification control can reduce NO_x by only less than 50% (Radojevic, 1998). Therefore, the adoption of post-combustion technology is important for making any significant reductions in NO_x emissions.

The SCR and SNCR technology are representative post-combustion processes. SCR technology is usually applied to thermal power plants with capacities greater than 200 MW and that work at a temperature in the range of 300 to 400 °C (Cofala and Syri, 1998). While the denitration efficiency of SCR is high (i.e., up to 80–90%), one problem is that catalyst pollutes the environment (Zhou et al., 2012). The ammonia used in the catalytic process can corrode the equipment, produce ash pollution, and damage the environment. SNCR is another technology used to control NO_x emissions from coal-fired power plants. Since it does not require any catalyst, the denitration process produces no pollution. It incurs a lower investment cost and can be applied to any size of unit. On the other hand, it requires a high working temperature (i.e., 870 – 1100 °C), and its rate of denitration efficiency is usually lower than 40% (Liang et al., 2011).

Table 1 summarizes the characteristics of these two technologies. SCR requires catalyst, while SNCR does not, and there is a pressure loss with SCR but not with SNCR. The removal efficiency of SCR is as high as 80%, while that of SNCR is 40% at most. The construction cost of SCR is higher than that of SNCR. SCR produces ammonium hydrogen sulfate, while SNCR does not (Zhou et al., 2012). In addition to the SCR and SNCR technologies, a hybrid of these two technologies, SNCR - SCR, is used in Chinese thermal power plants (Liang et al., 2011). It is more environmentally friendly and cost-effective than SCR and is more denitration-efficient than SNCR. SCR and SNCR technologies were initially installed in the early 2000s, while the first SNCR–SCR technology was installed in 2006 (Chinese Ministry of Environmental Protection, 2014b). As we will see in a later section, a large proportion of these technologies were installed after 2010.

Table 1
Comparison of SCR and SNCR technology.

	SCR	SNCR
Catalyst	Yes (30% of investment)	No
Pressure loss	Yes	No
Size	Large	Small
Reduction process	Outside of the boiler	Inside of the boiler
Efficiency	80%	25–40%
Cost of construction	High	Low
Side effect	Produce NH_4HSO_4	–