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Emissions trading and technology adoption: An adaptive agent-based analysis of thermal power plants in China

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A B S T R A C T

Market-based environmental policy can strongly affect both technological advancement and the diffusion of less pollution-intensive or less cost-intensive abatement technologies and facilities. This study applied an agent-based model to examine the effects of an emissions trading system on the NOx technology adoption of power plants in China. The results indicate that an emissions trading system influences obsolete technologies with lower removal levels, but it does not promote the adoption of the most advanced technology. Most power plants will adopt the best available technology under an emissions trading program. In addition, national emissions trading encourages power plants to adopt technologies with relatively higher removal rates compared with separate regional emissions trading systems, but a national program decreases the adoption of most advanced technology. Further, initial allowance allocations based on concentration standards rather than on generation performance standards may promote power plants to adopt the newest technologies more quickly.

1. Introduction

The popularization of the emissions control technologies may play an important role in achieving pollution control targets without producing serious economic damages. An appropriately designed environmental policy can strongly affect both technological advancement and the diffusion of less pollution-intensive or less cost-intensive abatement technologies and facilities (Jaffe et al., 2002; Löschel, 2002; Requate, 2005). However, both theory and experience suggest that the private sector, the main operator of these technologies, would not exert great effort to adopt new pollution control technologies without well-considered environmental management policies, as it aims to maximize its production profits or minimize its control costs (Requate and Unold, 2003; Tarui and Polasky, 2005).

Addressing pollution control should stimulate the private sector to adopt advanced abatement technologies and install facilities that have higher pollutant removal rates. Emissions standards, taxes and trading are relevant environmental policy instruments that are currently in place or under consideration for use somewhere in China. Emissions standards are typical command-and-control policies that set various concentration limits for pollutants discharged by emissions sources. Because emissions standards are set based on national average control levels, sources whose emissions concentrations are lower than this standard may not be encouraged to change their current control technologies, increase their operation efficiency or adopt technologies with higher removal rates. Emissions trading is a market-based instrument of which a cap-and-trade program (CTP) is the basic form. Policymakers set a cap on total emissions of certain pollutant and distribute initial allowances to emissions sources that sum up to the cap based on certain regulations. If sources can reduce emissions at lower marginal abatement costs than can other sources, they can sell their excess allowances in the trading market, while sources with higher marginal abatement costs can buy additional allowances from this market. By trading emissions allowances in the market, the private sector can reduce its control costs and increase its profits. Meanwhile, it has been proven that well-considered CTPs can reduce emissions (Burtraw and Mansur, 1999; Ellerman, 2000; Ellerman and Harrison Jr., 2003) and effectively reduce national average abatement costs (Burtraw et al., 1997; Burtraw et al., 1998; Burtraw et al., 2001). Under a CTP, if the marginal abate-

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ment costs of installing facilities with higher emissions removal rates are higher than the costs of purchasing allowances from other emissions sources in the trading market, then the private sector will buy emissions permits to satisfy its emissions requirement. On the one hand, an emissions trading system may decrease some firms' incentives to adopt new technologies (Malueg, 1989). On the other hand, if the prices of emissions allowances in the market are higher than the marginal costs of installing new abatement technologies, companies may be encouraged to adopt technologies with higher pollutant removal rates to achieve their emissions control goals. Thus, whether CTP suppresses or promotes technology adoption, and in turn affects technological progress, remains an open question.

Emissions trading can effectively reduce pollutant emissions at lower total costs and is regarded as a key instrument in pollution control. This market-based mechanism is currently used in the US, Europe, and other countries (Heindl and Löschel, 2012). In the 1970s, the US Environmental Protection Agency (EPA) implemented "Offset Policy" and "Bubble Policy", which were early approaches to emissions trading. In 1990, under Title IV of the "Clean Air Act", sulfur trading entered into force, and the NOx Budget Program aimed to reduce NOx emissions in the northeastern US beginning in 2003. Regional trading programs, such as "Regional Clean Air Incentives Market" (RECLAIM) in California, were also implemented. To date, the European Union Emissions Trading Scheme (EU ETS) is the largest greenhouse gas (GHG) abatement program in the world (Kossoy and Guigon, 2012). In 1992, an emissions trading program for particulate matter entered into force in Santiago de Chile (Montero et al., 2002). In 1997, the Kyoto Protocol, an international emissions trading scheme that required GHG emissions reductions of 5%, on average, over the 1990–2012 period was expected to significantly reduce compliance costs (Böhringer and Löschel, 2002). Beginning in the late 1980s, China began to implement pilot programs for emissions trading. However, due to inadequate legal and regulatory conditions; imperfect monitoring, supervisory and management mechanisms; and implementation barriers, progress in China was very slow (Jinnan et al., 2009) during the early period. During the first stage (1988–1995), 16 cities were selected to pilot the air pollutant emissions permit system. Another 6 cities have followed suit since 1994, which produced some rudimentary experience, albeit primarily conceptual. Then, during the ninth Five-year Plan period (1996–2000), the State Council approved the "National Plan for Total Emissions Control of Major Pollutants" submitted by the State Environmental Protection Administration (SEPA). Outlining the nationwide implementation of an emissions permit system and total emissions control, the plan provided an institutional foundation for emissions trading practices in China. During this period, the emissions trading programs achieved significant progress. The 10th Five-year Plan (2001–2005) formalized total emissions control, allowing multiple emissions trading programs to be implemented and experiences to be gathered. Recently, to effectively address GHG emissions, China, the largest carbon emitting country in the world, selected 7 provinces and cities to launch carbon emissions trading pilot programs: Beijing, Tianjin, Chongqing, Shanghai, Hubei, Guangdong and Shenzhen (NDRC, 2011). Through these pilot programs, China reduced pollutant emissions and encouraged companies to engage in pollution control to a certain extent.

A large body of literature analyses the relationship between environmental regulation and innovation, generally finding that the economic instruments, such as pollution taxes or tradable permits, can provide more efficient technology adoption incentives than conventional regulatory standards, such as pollutant emissions standards (Zerbe, 1970; Downing and White, 1986; Milliman and Prince, 1992; Fischer et al., 2003; Jaffe et al., 2003). Jaffe et al. provide a broad review of the literature on technological change and the environment (Jaffe et al., 2003). Zerbe (Zerbe, 1970), Orr (Orr, 1976), and Magat (Magat, 1978) provide early theoretical discussions of the firm's incentives to innovate and adopt pollution-reducing technology. Milliman and Prince (Milliman and Prince, 1992) consider the effects of different instruments when market effects are taken into account. Laffont and Tirole explore the use of spot and future markets for pollution permits in inducing optimal rates of diffusion and innovation (Laffont and Tirole, 1996a; Laffont and Tirole, 1996b). In addition, with the implementation of CTPs, several papers have been written to explore the effects of emissions trading on technological change, including effects on technology adoption and process changes in the private sector. Kerr et al. use a duration model applied to a panel of refineries from 1971 to 1995 to explore policy-induced technology adoption and find that tradable permit systems used during phasedown (e.g., the US petroleum industry's phasedown of lead in gasoline) provide incentives for more efficient technology adoption decisions (Kerr and Newell, 2003). Ellerman et al. evaluate of compliance costs and market performance under the US Acid Rain Program finding that approximately half as many scrubbers as originally anticipated were installed during Phase I of SO_2 trading (Bailey and Elizabeth, 1997). During Phase II, Ellerman also carries out ex post evaluation of tradable permits and estimates that 37% of emissions reductions were due to SO_2 scrubbers (Ellerman, 2003). Popp uses patent data to study innovation in flue gas desulfurization units across 1990Clean Air Act indicating that the move to cap-and-trade regulation for SO_2 in the late 1990s was accompanied by an improvement in the SO_2 removal efficiency of scrubbers (Popp, 2003). The above researches focus on ex post evaluation of the effects on technology adoption under emission trading policy using statistical data and analyzing this effect through building theoretical economic models.

Traditional economic theories and analyses only consider ideal representative participants in static equilibrium states (Tesfatsion, 2006). However, in real economic situations, the dynamic behavior and interactions between different firms in the emission trading market are very complicated and may often seem irrational (Mizuta and Yamagata, 2001). The static and homogeneous methods are very difficult to analyze dynamically changing situations invo1ving heterogeneous agents. Agent-based model is a computerized simulation of a number of agents and institutions, which interact through prescribed rules. It can handle a wider range of nonlinear behavior than conventional equilibrium models (Farmer and Foley, 2009), and model of many heterogeneous real world agents (such as households, businesses, and governments) as individual software programs, in which the dynamic environmental, political, economic, and social behaviors are captured, and a virtual replica of the real world is created (Peters and Brassel, 2000). Because the agent-based model can capture the complex trading mechanisms of different agents, purchasing behavior and their interactions, which are beyond the scope of traditional analysis approaches, this method has been widely applied in energy market and energy policy simulation, especially in the study of electricity (Bunn and Oliveira, 2003; Bunn and Oliveira, 2007; Rai and Robinson, 2015) as well as emissions trading markets (Mizuta and Yamagata, 2001; Bonabeau, 2002; Tesfatsion, 2006; Genoese et al., 2007; Cong and Wei, 2010; Tang et al., 2015; Lee and Han, 2016). In this paper, we tried to analyze the effect of emission trading policy on technology adoption of power plants. We model the dynamic decision-making behavior of each power plant with specific feature, which can not be reflected by traditional static equilibrium model. For example, each power plant might decide to install control technology itself or to buy emission permits from the trading market according to its current situation, the state of the other power plants and the rules governing its behavior. However, the agent-based model can keep track of many firms' interactions, and capture the complex trading

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