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Policy Conflicts and the Performance of Emissions Trading Markets: An Adaptive Agent-based Analysis

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POLICY CONFLICTS AND THE PERFORMANCE OF EMISSIONS TRADING MARKETS: AN ADAPTIVE AGENT-BASED ANALYSIS

Bing Zhang
Yongliang Zhang

EXECUTIVE SUMMARY

Emissions trading is considered to be a cost-effective environmental economic instrument for pollution control. However, pilot emissions trading programs in China have failed to bring success in the campaign for pollution control. Using the Jiangsu SO_2 emissions trading market as a case study, this research develops an agent-based model of the emissions trading market. By combining the policy conflicts of the agent-based model, the market performance of the Jiangsu SO_2 emissions trading market was examined.

We found four main policy conflicts: a) China's regional total pollution control policy; b) pollution discharge standards; c) the Electricity Generation Right (EGR); and d) the pollution discharge levy. These policy conflicts were found to have a negative impact on the Jiangsu SO_2 emissions trading market. The constraints of the regional total pollution control policy had the most significant impact on market performance. Taking all of the four policy conflicts into consideration, the cost savings of total SO_2 pollution control via emissions trading was limited, at only 4.79% of the total emissions control costs.

1.0 INTRODUCTION

Growing criticism from both inside and outside China is forcing the country to reduce pollution to an acceptable level. The State Environmental Protection Agency (SEPA) set a target for the 11th Five-Year Plan (2006-2010) of reducing SO_2 emissions by 10% to 22.95 million tonnes through new desulphurization technologies, as well as via a 20% reduction in SO_2 in two control zones: an acid rain control zone and a sulfur dioxide control zone. The control zones were created by the State Council on 12 January 1998 and include 175 cities and other areas, collectively spanning 1.05 million m^2 or 11% percent of China's total land mass. A variety of policy options are available for SO_2 reduction and the most effective and cost-effective policies will need to be chosen before China can meet its air quality standards. Emissions trading uses a market-based mechanism and is considered to be an effective instrument for encouraging emissions reduction at the lowest possible economic cost. The Chinese government has embraced some pilot projects in emissions trading in order to explore an appropriate policy design for SO_2 emissions control in China.

In recent years, environmental authorities in China have expressed an interest in the use of tradable permits (TPs) as a regulatory instrument to control SO_2 emissions. This interest arises from the increasing attention given throughout the world to the use of market-based instruments as a means of achieving environmental objectives, and also the success of tradable permits in the United States in reducing and limiting SO_2 emissions. Moreover, the low cost of market-based instruments is particularly appealing in China where social needs take priority and income level is relatively low (Ellerman 2002).

Emissions trading allows regulated facilities to transfer emissions allowances. This leads to the distribution of emission reductions amongst facilities, which equates to the marginal cost of emissions reduction (Burtraw *et al.* 2005). This therefore minimizes the aggregate costs of achieving any given reduction in total emissions. More than four decades ago Crocker (1966) and Dales (1968) developed the idea of using transferable discharge permits to allocate the pollution-control burden amongst firms or individuals. Montgomery (1972) provided rigorous proof that a tradable permit system could, in theory, provide a cost-effective policy instrument for pollution control. Later, economists promoted tradable permits as a policy alternative, but the concept was generally regarded as impractical despite its theoretically attractive properties. Only in the 1980s were tradable permits implemented and declared a success, mostly in the United States (Ellerman 2005). To date, there are many instances of using this type of incentive mechanism in the USA and Europe, such as USEPA's emissions trading program (Tietenberg 1985), water quality permit trading (Hahn and McGartland 1989), CFC trading (Hahn and McGartland 1989), the RECLAIM program in the Los Angeles metropolitan region (Harrison 1999), and tradable development rights for land use (Weber and Adamowicz 2002). Article 17 of the 1997 Kyoto Protocol describes an international emissions trading system for greenhouse gases (GHG) as one of four cooperative mechanisms to achieve GHG targets by 2008-2012 (Dewees 2001; Soleille 2006; Weber and Matthews 2007).

The ex-post analysis of emissions trading programs has found that cost savings have been smaller and the trades fewer than might have been expected at the outset of the programs (Atkinson and Tietenberg 1991; Tietenberg 2006). Researchers have pointed out that the institutional arrangements or design of the emissions trading policy has a decisive impact on its cost-effectiveness, based on ex-ante analysis and ex-post analysis in other counties (Woerdman and van der Gaast 2001; Zhang *et al.* 2010a). These design issues include transaction costs (Stavins 1995; Zhang *et al.* 2011), spatial and temporal dimension mechanisms, initial allocations (Liu *et al.* 2012), market power, monitoring, and enforcement among others (Antes *et al.* 2008; Tietenberg 2006). In addition, most of the ex-ante research separated the emissions trading systems from existing environmental regulation systems. However, existing environmental regulation also has an impact on an enterprise's decision making, as well as its emissions trading behavior. For example, in the United States' Acid Rain Program, all areas of the country must meet national health-based air quality standards that are separate from the cap and trade program's requirements. Thus, policy conflict or policy incoordination is thought to be an important barrier to introducing a new emissions trading policy in China (Chang and Wang 2010; Tao and Mah 2009; Zhang *et al.* 2010b; Zhang *et al.* 2012).

Due to differences of interest and value objectives among policymakers, policy conflict is inevitable. This conflict results in contradictions and incompatible policies in the context of a complex policy network (Colebatch 1998; Colebatch 2005). Governments in counties experiencing transition often face policy conflicts when introducing a new public policy and developing it from theory through to practice (Colebatch 1998; Colebatch 2005). Such policy conflict seriously affects the systematic implementation and efficiency of a policy (Peterson and Rose 2006).

Emissions trading is a new environmental policy that has been discussed and introduced in many countries but has been used on only a limited basis in China due to a number of obstacles (Dudek *et al.* 2004). These obstacles include uniformity of abatement technologies across sources and the influence and lobbying of stakeholders in the existing pollution-control regime (Smith 1999). Policy conflict and incompatibility issues between the emissions trading policy and other environmental regulations, policies and instruments also appears to be an important factor hindering successful policy innovation (Smith 1999). The introduction of emissions trading requires some recognition of the deficiencies of existing approaches that might be resolved through the introduction of a new instrument into the policy portfolio. Emissions trading policy must also be capable of operating alongside existing policy instruments. However, there are obvious issues surrounding the compatibility and coordination of emissions trading policy with other instruments (OECD 2006; Smith 1999).

Related factors or policies, such as the price of electricity or environmental quality standards, have been examined to investigate their impact on the performance of emissions trading programs. In the energy market, both the price of coal and the price of electricity will significantly affect the performance of an emissions trading market. Zhang (2007) finds that a 1% increase in electricity price volatility, measured by the annualized standard deviation of percentage price change, is associated with an average decrease in the annual emissions rate of 0.88%. Boutaba *et al.* (2008) also found that an increase in the electricity price tends to decrease the demand for electricity, which in turn decreases SO_2 permit prices in the United States. For water pollution trading programs, water quality standards should be taken into consideration as a constraint on emissions trading. Researchers have provided different emissions trading frameworks meeting different water quality standards (Cao and Ikeda 2005; Ng and Eheart 2005; Ning and Chang 2007), which will increase transaction costs and reduce cost savings.

China's regulatory system for pollution control has been in existence for quite some time so some existing policies will impact on a new environmental policy instrument (Chang and Wang 2010; Guttman and Song 2007; Tao and Mah 2009). This research tried to examine whether an emissions trading policy is compatible with existing industry policies, and how. The SO_2 emissions trading program in Jiangsu Province was used as the case study for exploring policy conflicts between emissions trading and other related polices. We also provide a basic simulation model of emissions trading and related policies that have an impact on emissions trading. The simulation results of the SO_2 emissions trading program of Jiangsu Province is presented in Section 3, and a discussion of the impact of policy conflicts on emissions trading policies is also provided. Finally, our conclusions are outlined in Section 4.

2.0 METHODOLOGY

2.1 Emissions Trading in China

In the early 1980s, China began discussing and piloting new emissions trading projects. The government carried out case studies on the compensated transfer of emissions permits. However, due to legal and regulatory constraints, limited experience, and implementation issues, these experiments were primarily conceptual. During the 9th Five-Year Plan period, significant progress was made when total emissions control (TEC) was promoted nationwide. Interest in emissions trading had grown noticeably by the 10th Five-Year Plan period when TEC became more formal.

In 1999 SEPA and the US EPA cooperated on a study to assess the feasibility of introducing a SO_2 cap and trade scheme in China. The study encompassed wide-ranging discussions on the theories, conditions, foundations, and methods of cap and trade. The project further explored the opportunities and obstacles to implementing a SO_2 cap and trade scheme in the Chinese power sector, and Benxi and Nanjing were chosen as two pilot areas. In 2002 SEPA began the 4+3+1 program, choosing Shandong, Jiangsu, Shanxi and Henan provinces, Shanghai and Tianjin municipalities, and Liuzhou city, and China Huaneng Group as pilot areas for the pursuit of total emissions control and emissions trading (SEPA 2002). Since 2006, the Ministry of Environmental Protection (MEP) and the Ministry of Finance (MOF) of China have selected seven provinces for a pilot water pollution trading (WPT) program. By 2011, more than 10 provinces and cities had carried out emissions trading programs (Table 1).

Table 1. Key emissions trading programs in China, 2007-2011

Programs	Start-time	Pollutants
Hangzhou in Zhejiang Province	2007	SO_2 and COD
Tongxiang in Zhejiang Province	2007	SO_2 and COD
Jiaxing in Zhejiang Province	2007	SO_2 and COD
Jiangsu Province (Tai Lake Basin)	2008	COD
Hubei Province	2008	SO_2 and COD
Tianjin Municipality	2008	SO_2 and COD
Shaoxing in Zhejiang Province	2008	SO_2 and COD
Heilongjiang Province	2009	SO_2 and COD
Chongqing Municipality	2010	SO_2 and COD
Hunan Province	2010	SO_2 and COD
Hebei Province	2010	SO_2 and COD
Shanxi Province	2010	SO_2 and COD
Neimenggu Province	2011	SO_2 and COD

There are limited examples of emissions trading in the pilot areas, and they are unlike those observed in an active market. However, in 2006, emissions from 24 power plants exceeded their permits and 21 power plants had an emissions surplus. Some old power plants have large emission allowances and have lower SO_2 emission abatement rates than others. The flexibility of the current emissions trading policy, conflict between different environmental policies, and administrative interference are considered the main barriers to the success of SO_2 emissions trading programs in China (Dudek *et al.* 2004; Tao and Mah 2009).

In addition, as previously mentioned, other researchers have pointed out that the institutional arrangements (or design) of the emissions trading policy has a decisive impact on its cost-effectiveness, based on ex-ante analysis and ex-post analysis in other counties (Woerdman and van der Gaast 2001). These design issues include transaction costs, spatial and temporal dimension mechanisms, initial allocations, market power, monitoring, enforcement, and so on (Antes *et al.* 2008; Tietenberg 2006). Therefore, the question *"is there a need to implement an emissions trading policy in China and, if so, how should this be done?"* should be carefully considered. Since institutional arrangements or policy design will dramatically affect the cost-effectiveness of emissions trading (Tao and Mah 2009), examining the cost-effectiveness of the emissions trading market under different institutional arrangements or policy designs is crucial for designing an effective SO_2 emissions trading policy in China.

2.2 Research Area

This research chose the Jiangsu Province (Figure 1) SO_2 emissions trading market as a case study. Jiangsu is the only province in China that has both an acid rain control zone and a sulfur dioxide control zone. In its 10th Five-Year Plan, the Jiangsu annual average SO_2 concentration increased, as did the acid rain frequency. In 2005, the acid rain frequency reached 33.9%. In the 11th Five-Year Plan, central government required Jiangsu to reduce SO_2 emissions by 18% on the basis of the level recorded in 2005. In the new 12th Five-Year Plan, Jiangsu also planned to reduce 10% of SO_2 on the basis of the level recorded in 2010. Emissions trading is considered a feasibile mechanism to achieve total pollution control targets with lower economic costs. A new SO_2 emissions trading measure was issued by the Jiangsu Environmental Protection Department (EPD) in 2012.

Figure 1. Location of Jiangsu Province

According to the design of Jiangsu's emissions trading program, every power plant is issued a permit according to their SO_2 discharge efficiency; power plants should not discharge more SO_2 than their permit allows. The permit can be traded between power plants. The Jiangsu EPD also established an emissions trading electronic bulletin system that allows the emissions of power plants to be identified and matched so that opportunities for trades can take place. Power plants can also see the permit price of the emissions trading market through the electronic bulletin system. Banking is not clearly regulated in the policy. We will analyze the permit price dynamics when banking is allowed.

2.3 Agent-based Model of Jiangsu's SO_2 Emissions Trading Market

Individual pollution control behavior finally results in emissions trading policy performance and local ambient air quality. Traditional economic theories and analysis have only considered idealized representative participants in equilibrium states (Tesfatsion 2006). However, in real economic situations, the dynamic behavior and interactions between firms in emissions trading systems are complicated and may often seem irrational (Mizuta and Yamagata 2001b). It is very difficult to analyze dynamically changing situations involving heterogeneous subjects using such static and homogeneous methods.

An alternative approach is the agent-based simulation approach. Agent-based modeling, an approach which simulates the behavior of a complex system in which agents interact with each other and with their environment using simple local rules, is gaining popularity and is being used in many areas (Bonabeau 2002). Adaptive agent models were first proposed by von Neumann (1966) in *A Theory of Self Reproducing Automata* and remain in their nascence today. The first application of agent-based modeling to social science problems was accomplished by Thomas Schelling. His work is precisely summarized in his now classic book *Micro-motives and Macro-behavior* (Schelling 1978).

While referring to emissions trading markets, Mizuta and Yamagata (2001a) developed an Artificial Society with Interacting Agents (ASIA) model to simulate the Kyoto-protocol GHG emissions trading. In ASIA, the auctioneer sends each agent a Request for Bid (RFB) containing price signals. Based on this signal, the regular agents decide their levels of production for that time step and speculators update their estimates. The agents then send bids to sell or buy. Finally, the market treats the submitted bids as a sealed-bid double-auction and determines a single price that maximizes the total amount of emission permits to be exchanged. Genoesea *et al.* (2007) applied an agent-based simulation model to analyze the integration of different proportions of the daily actual emission allowance price into the bidding process for power plants on the German spot market and the resulting effect on the electricity prices for the year 2005. Zhang *et al.* (2008) also examined the influence of transaction costs on the regional emissions trading system of Wujin County, Jiangsu Province, China, using agent-based modeling (ABM). Thus, this research will apply ABM as a new instrument and framework to analyze emissions trading policy.

2.3.1 General emissions trading framework

A simple process of a cap and trade system can be explained as follows:

- A regulator determines the scope of the system, e.g. regions and sectors, and sets a limit or cap on the total emissions.
- Economic agents are provided with emissions rights based on certain standards, and each agent is required to hold the rights corresponding to its emissions.
- If an economic agent does not hold enough emissions rights, it has to abate its emissions or buy emissions rights from agents who emit fewer emissions than the rights that they hold, in order to comply with the regulation.

Agents (power plants in this paper) aim to abate SO_2 emissions to levels below their emission rights and to maximize profit. Each power plant considers the marginal profit (MP) function, SO_2 emissions, emission rights, strategies, and existing environmental regulations. Firms are free to trade permits at any time and may meet government standards by exercising pollution control and by possessing permits for their residual emissions. We assume that all power plants are profit-maximizing agents, nobody exercises market power, and perfect monitoring and enforcement are available to the environmental regulator.

We consider e_i as the unconstrained emissions in units per year; r_i as the pollution reduction in units per year by firm i; A_i as the quantity of permits in units per year allocated to source i; and x_i as the amount of emissions traded. Here, we assume that firms employ three compliance strategies: abatement of emissions, purchasing of allowances in addition to their initial allocation, and adjustment of output levels (Zhang 2007). Therefore, we have

$$x_i = e_i - r_i - A_i \qquad \text{(Equation 1)}$$

If $x_i = e_i - r_i - A_i > 0$, firm i will buy emission permits; contrarily, firm i will sell emission permits. The benefit of firm i is

$$\pi_i = R_i - c_i(r_i) - px_i \qquad \text{(Equation 2)}$$

Here, R_i is the received (exogenous) revenues of firm i. $c_i(r_i)$ is the emission abatement costs, for which $c_i'(r_i) > 0$ and $c_i''(r_i) > 0$. The total cost of emission control is $c_i(r_i) + px_i$. p is the price of emission permits. In each time period, the firm decides the electricity output (g_i) and chooses the amount of coal (q_i). Suppose electricity prices is p_e, we have

$$R_i = g_i(q_i)p_e - C_i(q_i) \qquad \text{(Equation 3)}$$

The production function with fuels is represented by $g_i(q_i)$, which is assumed to be concave and twice differentiable everywhere (Zhang 2007). We assume that electricity generation is described by a homogenous first-degree Cobb-Douglas production function, $g_i(q_i) = Gq^k$, where G is a productivity parameter and $0 < k < 1$; k is a constant determined by technology and power capacity. In addition, for the model to be tractable, we assume that the operation costs (C_i) are continuous and linear in p_c.

$$C_i(q_i) = \varphi p_c q_i \qquad \text{(Equation 4)}$$

Here, p_c is the coal price and φ the parameter of operation costs. Thus, the benefit of firm i is

$$\pi_i = g_i(q_i)p_e - \varphi p_c q_i - c_i(r_i) - px_i \qquad \text{(Equation 5)}$$

We also assume θ_i is the emission removal rate, thus $1 - \theta_i$ is the pollution discharge rate. Thus

$$r_i = e_i\theta_i = \alpha_i\theta_i q_i \qquad \text{(Equation 6)}$$

In addition, c_i is the function of θ_i and q_i, and is assumed to be concave, twice differentiable everywhere ($c_i'(\theta_i) > 0$, $c_i''(\theta_i) > 0$).

$$c_i(r_i) = c_i(\theta_i\, , q_i) \qquad \text{(Equation 7)}$$

The emission abatement costs are further assumed to be a function of the emissions reduction and emissions reduction rate:

$$c_i = \emptyset_i \alpha_i q_i \theta_i \kappa^{\frac{1}{1-\theta_i}} \qquad \text{(Equation 8)}$$

Here, κ and $\emptyset_i$ are the parameters of the emission abatement costs function, and θ_i is the emissions abatement rate. All power plants are assumed to have the same value of κ and different values of $\emptyset_i$. $\alpha_i q_i \theta_i$ is the emissions reduction for power plant i.

When a firm is planning to participate in an emissions trading market, transaction costs are inevitable. Firms need to find trading objectives, audit and calculate abatement costs, negotiate the trading price, obtain the trade approval, etc. All of these elements will cause transaction costs. Here, we assume two parts of transactions cost: a) fixed cost and b) costs related to gross emissions trading (Collins and Frank 1991). Thus, in this paper, we define the transaction costs as

$$T(x_i) = a + bx_i \qquad \text{(Equation 9)}$$

Here, a is the fixed part of transaction costs, and bx_i is related to the emission trading quantity. Fixed costs can include administrative costs, e.g. additional monitoring costs for trading and approval costs. The government provides an emissions trading center to reduce transaction costs. However, there are costs in building and maintaining the emissions trading center, which are transferred to trading firms as a trading tax.

Finally, in most previous studies, an emissions discharge fee (or emissions discharge tax) is separated from the emissions trading market. Firms do not need to pay any tax or fee for emissions discharge under the cap. However, there are also some counties, such as China, which have an emissions fee/tax system. According to China's current environment levy system, we assume the emissions fee/tax standard is p_d. Thus, firm i should pay the emissions discharge fee/tax (f_e), which is

$$f_e = a_i q_i (1 - \theta_i) \times p_d \qquad \text{(Equation 10)}$$

Thus, at each period, a firm observes the electricity price (p_e), permit price (p), emissions discharge fee (p_d), price of carbon fuel (p_c), and allocated permits (A_i). Each firm adopts a strategy in each time period that is optimal from the firm's perspective in that period. Thus, the firm's strategy is a map from the Markov state $\wedge = \{P,A\}$ to choice variables $\{q_i, \theta_i, x_i\}$, where P is a price vector, i.e., $P = \{p_e, p, p_c, p_d\}$. Here, θ_i is the emissions removal rate and q_i represents coal consumption; $\{q_i, \theta_i, x_i\}$ represents the three compliance strategies: abatement of emissions, purchasing of allowances in addition to initial allocation, and adjustment of output levels. Let $\pi_i(P, A_i)$ denote the value of firm i. The maximization problem for the firm can be written as

$$\pi_i(P, A_i) \equiv \max_{\theta_i q_i x_i} [g_i(q_i)p_e - \varphi p_c q_i - c_i(r_i) - px_i - p_d a_i(1 - \theta_i)q_i - T(x_i)] \qquad \text{(Equation 11)}$$

$$\text{subject to: } A_i + x_i - a_i(1 - \theta_i)q_i = 0 \qquad \text{(Equation 12)}$$

$$\theta_i \geq 0 \qquad \text{(Equation 13)}$$

2.3.2 Process overview and scheduling

According to recent practice in emissions trading in China (Nie and Xu 2009), this research selects a continuous double-auction emissions trading market for further analysis. In the double auction emissions trading market, both sellers and buyers place a buy/sell limit order (including the maximal/minimal price and the desired/offered amount) at any time. When a new order matches the best waiting order of the opposite type, a trade is made (for the limit price of the counterpart); otherwise, the new order is placed on hold. The orders may also be cancelled by their submitters (Cliff 2000; Posada *et al.* 2005). All participants can learn from the previous bid-ask and adjust their next bid-ask amount and price. Thus, each agent's decision-making process consists of the following four main steps, which is also illustrated in Figure 2:

1. ***Step one: Determining an order.*** When a firm is participating in the emissions trading market for first time, or when it has been waiting for a couple of trading rounds, each firm considers an order on the basis of its marginal profit, emissions allowance, market price of emission permits, and expected price of emission permits. The first stage is the determination of the emission amount each firm expects to abate and trade in a year, based on the current market price (P). We assume that MP_A (Appendix 1) is the marginal profit of a firm when the amount of emissions discharge ($E = aq(1\text{-}\theta_i)$) is equal to the firm's allowance (A). There are three types of choice according to the current emissions price of each firm. If its MP_A is higher than the current emissions price (Type A), then the firm should be a buyer. If its MP_A is lower than the current emissions price (Type B), then it should be a seller. If its MP_A is equal to the current emissions price (Type C), then it should be neither a seller nor a buyer until the price changes.

   Considering Type A, each firm selects a strategy, determines a bid amount, and calculates the MP to determine a bid price. Because the actual trading amount is uncertain when an order is considered and all of the agents are risk-neutral, the optimal bid price is less than P when the bid amount is $E_p\text{-}A$. Here, E_p represents the emission discharge when the marginal profits are equal to p and p is chosen as the bid price. Thus, buyers will determine the bid price of p, and the bid amount will be $E_p\text{-}A$. In the same manner, the sellers will determine the bid price of p, and the bid amount will be $A\text{-}E_p$.

2. ***Step two: Making an order.*** All the agents have determined an order but only some actually make it in accordance with its strategy. We assume that each agent has a constant activation probability of 25% per round. In other words, 25% of the agents are randomly chosen to bid in each round (Posada *et al.* 2005; Walsh *et al.* 2002).

3. ***Step three: Accepting an order.*** The buyer with the highest bid price is initially matched with the seller with the lowest asking price, as long as both sellers and buyers exist and the highest bid price to buy is not lower than the lowest bid price to sell (Nicolaisen *et al.* 2001). The purchase price would be the average of the highest bid price of buyers and the lowest bid price of sellers. In addition, if the buyer's and the seller's bid amounts do not match, then the buyer's bid is matched with the seller's bid such that the quantity of tradable permits is the minimum of the two amounts: the bidding amount of the

buyer and the asking amount of the seller. The carryover amount to buy or sell is then calculated, and the next pair is matched in the same manner.

4. ***Step four: Learning from previous orders.*** The repeated auction constitutes an environment where the bidders can obtain and utilize information from previous auction results. Cliff indicated that the price convergence of zero-intelligence traders is predictable from *a priori* analysis of the statistics of the system, so more complex bargaining mechanisms or some "intelligence" is necessary for traders (Cliff and Bruten 1997). Consequently, a type of agent with simple machine learning techniques was developed and is referred to as a zero-intelligence plus (ZIP) agent. Further experiments showed that ZIP agents outperform their human counterparts (Das *et al.* 2001). Therefore, in this research, we endow agents with ZIP ask-bidding strategies.

   According to ZIP strategies, agents in the emissions trading market will adjust their profit margin and bid price according to their previous bidding. If there was a transaction in the last round and the agent was not the winner, or there was no transaction, the agent decreases the profit margin in the current round. Contrarily, the winner has a greater profit margin in the current round. Details regarding ZIP strategy can be found in Appendix 2.

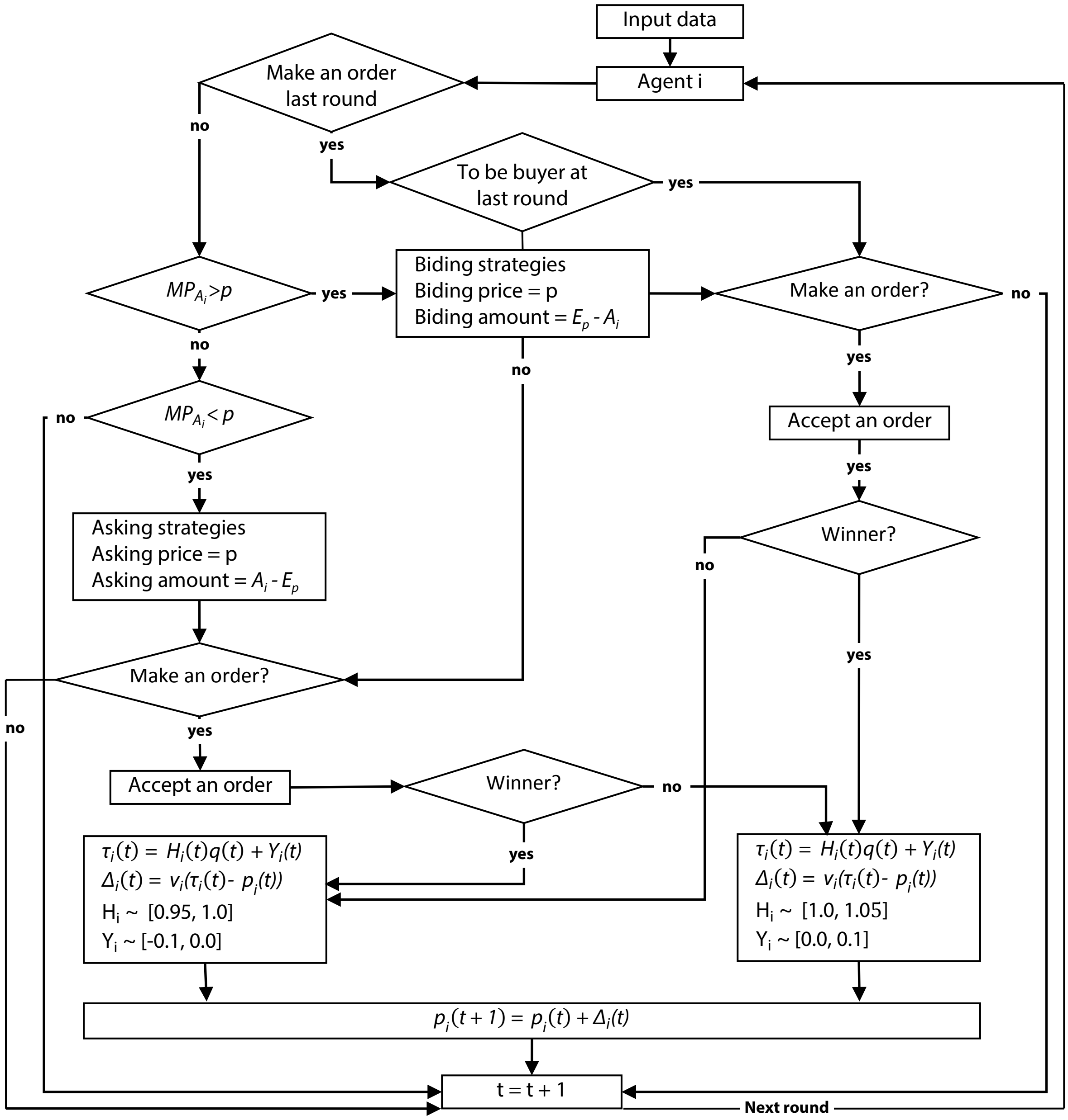

Figure 2. Flow diagram of model processes

2.4 Policy Conflicts of Emissions Trading Policy in China

2.4.1 Regional total pollution control policy

Ten percent (10%) of China's pollution reduction target is to be split between the provinces. Provincial governments then allocate pollution reduction targets to different cities. To make sure that the target is met, central government sets up national agendas, and therefore central government is the most important decision-maker in mitigating pollutant emissions. However, the commitment of central government is not significant enough to actually realize serious mitigation. The Ministry of Environmental Protection (MEP) and other central government agencies are mainly responsible for enacting policies, while enforcing them is largely left to local governments (Xu 2011).

In the 11th Five-Year Plan period, the Central Committee of the Communist Party (2006) issued new rules on the promotion of local communist party officers and local officials. These new rules emphasized that environmental protection is an important criterion for promotion. If failure to achieve environmental goals does not lead to demotion through the ranks, then leaders face the risk of being removed from their original positions to more junior positions. In contrast, achievement of the environmental protection goals can help promotion prospects (Xu 2011). In addition, in March 2008, SEPA was elevated to full ministry status, becoming the Ministry of Environmental Protection. It has been argued that this will give it equal status with other ministries and strengthen its position to pursue compliance with environmental regulations and laws (Cao *et al.* 2009). Environmental impact assessment (EIA) reports were formally established to punish regions that failed to meet environmental goals (SEPA 2008). Thus, making environmental protection a political task ensures local governments work according to the agenda outlined by central government, resulting in significant reductions of SO_2 and COD during 2006-2010. Thus, every region (city) in Jiangsu has a regional cap (RC_j) of SO_2 emissions. So the total amount of emissions discharged by all the power plants in region j should be no more than the regional cap (RC_j).

2.4.2 Pollution discharge standard

According to the pollution reduction requirement in the 11th Five-Year Plan, and the SO_2 emissions discharge standard (400 mg/m^3), every power plant should abate more than 85% SO_2 in Jiangsu (SCC 2007). Thus, in this research, we assume that power plants have their SO_2 reduction efficiency higher than 85%.

2.4.3 Electricity Generation Right

Power plants in China and Jiangsu also have to factor in the restriction of the Electricity Generation Right EGR_i, according to which power plants cannot generate more electricity than EGR_i. Before 2002, power plants had a long-term contract, the Power Purchase Agreement, with the electricity department. After 2005, the Electricity Generation Right (EGR) was allocated and is examined by government annually in the form of an administrative permit. Power plants cannot generate more electricity than their EGR.

2.4.4 Pollution discharge levy

The price-based and quantity-based approaches are two essential instruments used for pollution control. Several studies propose a hybrid policy in place of pure price or quantity controls (Roberts and Spence 1976; Weitzman 1978). Such mechanisms involve an initial distribution of tradable permits, with additional permits available from the government at a specified "trigger" price (Pizer 2002). All power plants should pay for the emissions discharge fee/tax in China. Thus, price-based and quantity-based approaches will be integrated in SO_2 emissions control.

2.5 Data Collection and Parameters Initialization

Our research examines the SO_2 emissions trading market of Jiangsu power plants. We analyzed all of the 45 power plants in Jiangsu. These power plants accounted for 75.7% of the SO_2 emissions discharge of the electric power industry in 2010. The initial allowance (A) and electricity price (p_e), coal consumption (q_i), and electricity generation and SO_2 emissions in 2006-2010 were collected from power plants and from the Jiangsu Environmental Statistics System. The emissions discharge fee (p_d) is set as CNY 1.26/kg according to regulation in Jiangsu. The coal price (p_c) is the average value of commercial coal and the power coal price in China.

Face-to-face interviews were carried out at the 45 Jiangsu power plants. Power plant personnel were asked about their implementation data, such as the initial allowance (A) and electricity price (p_e), coal consumption (q_i), and electricity generation and SO_2 emissions, etc. In addition, we asked them about how they intended to proceed with regard to pollution control targets, so that we could revise our previous agent-based model. The survey included the following questions: a) *Which factors will affect your decisions regarding emissions trading?* b) *How do you make an order if you want to trade your permits?* c) *How do you adjust your pollution control strategies by learning from pervious emission trades?* d) *Which factors/policies restrict your trades?*

In addition, some of the parameters of this research were calculated using original data from the 45 power plants. For example, the SO_2 generation parameter was calculated from coal consumption and SO_2 generation. The primary data/variables of power plants that we collected are listed below.

2.6 Simulation Platform

The agent-based model of emissions trading was implemented in NetLogo, a platform particularly suited to simulating a spatial logic driven by the MAS/CA approach (Wilensky 1999). NetLogo is a purpose-built ABM language and environment, which is intended for use in modeling a range of phenomena, especially complex systems with a large number of interacting parts.

According to the progress and the scheduling of the SO_2 emissions trading market (Figure 3), 45 agents were created in the NetLogo platform. The state variables of the agents (i.e., initial allowance A_i and SO_2 generation parameter q_i) were imported by NetLogo, while others were calculated by the agents dynamically (i.e., MP_i, etc.). The agents share global variables (i.e., p_d, etc.). The controlling variables that reflect different policy design scenarios were manually controlled by the model runners (Figure 3).

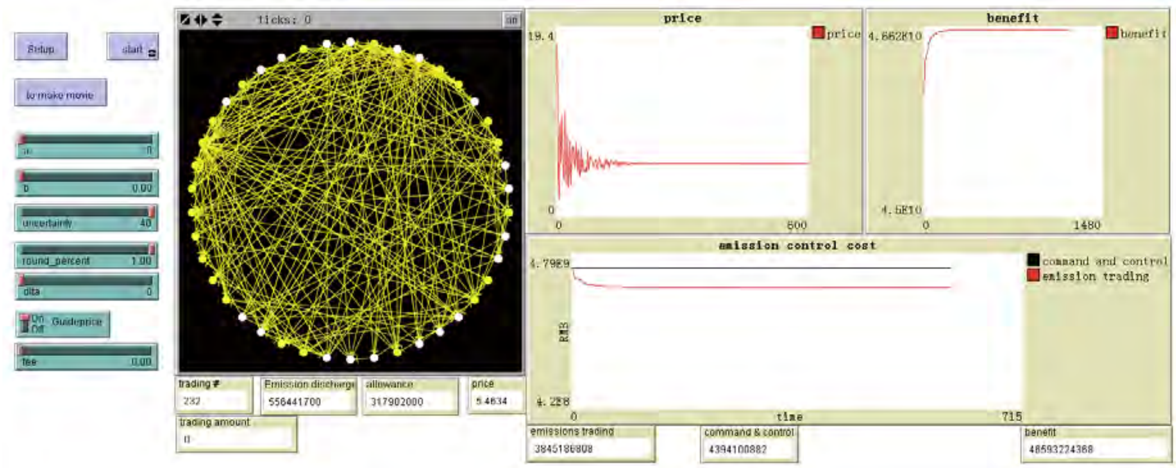

Figure 3. Jiangsu SO_2 emissions trading market

3.0 RESULTS AND DISCUSSION

3.1 Data Description and Parameters Initialization

Our research examines the SO_2 emissions trading market of power plants in Jiangsu Province. We looked at the main 45 Jiangsu power plants for analysis (Table 2). These 45 power plants account for 75.7% of the SO_2 emissions discharge created by the electric power industry in 2010, and 48,704 MW of power capacity.

Table 2. Power plants in Jiangsu Province

Area	Number	Power capacity (MW)	SO2 discharge (tonne)
Nanjing	6	4,335	32162
Wuxi	3	4,115	37731.4
Xuzhou	10	7,840	140490.4
Changzhou	2	1,640	13360
Suzhou	8	10,445	79447.2
Nantong	3	5,014	55794.4
Lianyungang	1	1,100	20288.9
Huaian	2	1,870	24182
Yancheng	2	1,120	18014
Yangzhou	2	3,560	44041.9
Zhenjiang	3	4,195	53430.4
Taizhou	2	3,200	-
Suqian	1	270	7102
Total	**45**	**48,704**	**526044.6**

3.1.1 Emission permits allocation

Jiangsu provincial government has allocated SO_2 emission permits according to the requirements of SEPA by Generation Performance Standard (GPS).[1] Integrating production technology, production efficiency, fuel quality, emissions treatment and emissions discharge, among others, Jiangsu provincial Environmental Protection Bureau (EPB) issued the allocation scheme of SO_2 emission permits of its power plants. The emissions allocation of each power plant is listed in Figure 4.

Some 526,044.6 t of SO_2 was discharged by the electric power industry in 2010. However, the total emissions allowance was only 317,902 t. Twenty-four (24) power plants' emissions discharge exceeded their emission permits. Twenty-one (21) power plants had a surplus, five of which were not operational (Figure 4).

[1] A Generation Performance Standard (GPS) is a mandate that requires load serving entities (LSEs) to manage their electricity generation portfolio in such a way as to achieve an average annual pound per megawatt hour emissions rate limit.

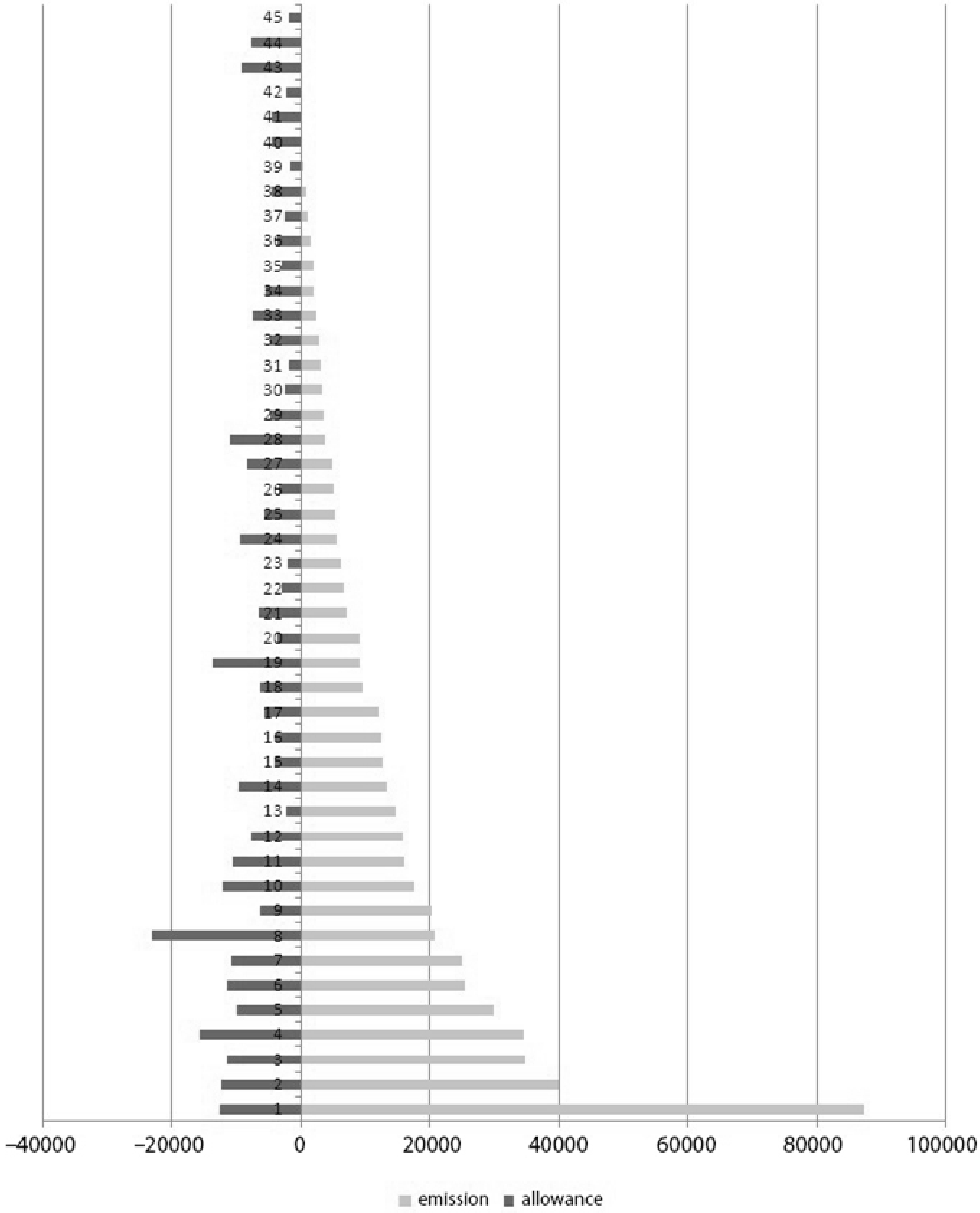

Figure 4. Emissions discharge and emission allowances of Jiangsu power plants

3.1.2 Electricity production function

Recall the Cobb-Douglas production function $g(q) = G_{q^k}$, where *G* is a productivity parameter, and *0 < k < 1*. *k* is a constant that is determined by technology and power capacity. Here we omit labor input *L*. We only collected two years of production data from the power plants. Here, we assume all of the power plants have the same value of *k*, so we can have the following regression equation:

$$\ln(g_i) = k\ln(q_i) + \ln G \qquad \text{(Equation 14)}$$

Here, ln*G* is constant. Using the real data of 45 power plants, the regression results are presented in Figure 5 and Table 3. The coefficient of ln*q* is the value of *k* in Equation 14. So we have *k* = 0.92011.

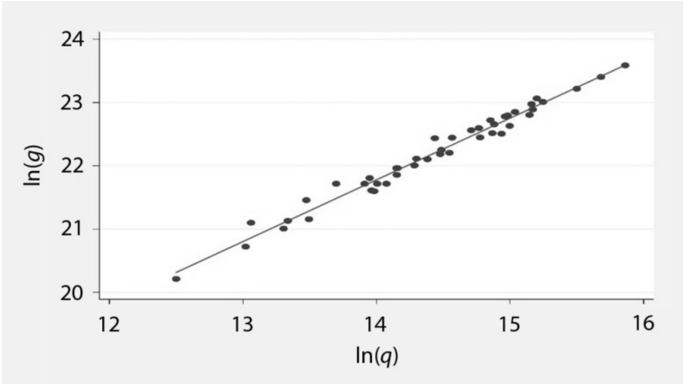

Figure 5. Fit-plot of ln(*g*) by ln(*q*)

Table 3. Regression results of ln(*g*) by ln(*q*)

Source	SS	df	MS		Number of obs.	45
Model	23.26688	1	23.2668777		F(1, 43)	2029.1
					Prob > F	0.0000
Residual	0.493063	43	.011466583		R-squared	0.9792
					Adj R-squared	0.9788
Total	23.75994	44	.539998653		Root MSE	0.10708
lng	Coef.	Std. Err.	t	P>t	[95% Conf.	Interval]
lnq	0.92011	.0216255	45.05	0.0000	0.930523	1.017747
cons	8.137779	.312608	26.03	0.0000	7.507345	8.768213

According to the equations, we get the parameter *k*. On the other hand, we can obtain *G* by:

$$G_i = \frac{g(q)}{q^k} \qquad \text{(Equation 15)}$$

The distribution of parameter *G* can be seen in Figure 6. Most power plants' *G* are around 6500.

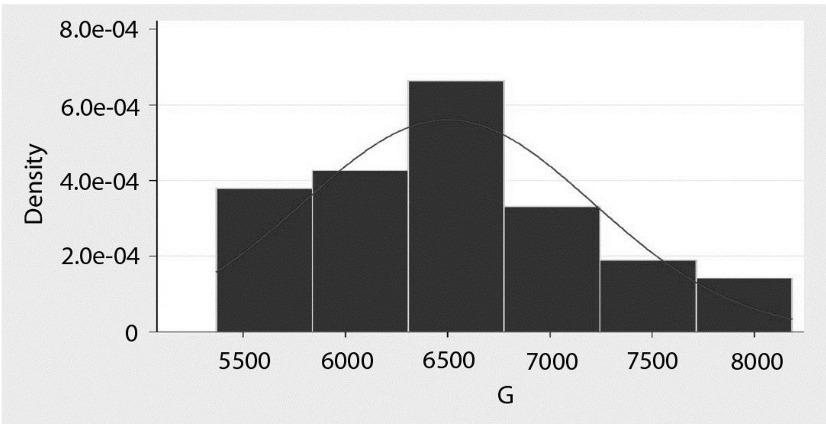

Figure 6. Distribution of parameter G

On the other hand, the power capacity of power plants is fixed, and we assume all power plants will not be allowed to invest in new power generators. Therefore, each power plant should have an upper limit of electricity generation and coal use. We assume the average production time is 8000 hours/year. So the upper limit of electricity generation (e_{ul}, KW) can be accounted for according to Equation 16.

$$e_{ul}=pc \times 10^6 \times 8000 / 1000 \quad \text{(Equation 16)}$$

Then, the upper limit of coal use can be calculated by:

$$q_{ul}=\left(\frac{e_{ul}}{G}\right)^{\frac{1}{k}} \quad \text{(Equation 17)}$$

Power loss rate

Between the power plant and the national grid, there is a loss of power. Therefore the usable amount of electricity is calculated as follows:

$$\widetilde{G} = (1 - r_{pl}) \times G \quad \text{(Equation 18)}$$

The average power loss rate in China is 7%, so power plants lose 7% of their generated power in transmission and $\widetilde{G} = 0.92011 \times G$.

3.1.3 Emissions discharge fee/tax

In accordance with the emissions reduction goals, Jiangsu provincial EPB and the Price Control Bureau adjusted the standard effluent charge from 1 July 2007. The new standard effluent charge costs companies CNY 1.26/kg for SO_2 discharged, instead of CNY 0.63/kg. In the future, the government may also adjust the emissions fee.

3.1.4 Emissions production and abatement

The 45 power plants consumed 81.01 million t of coal, and created 962.2 thousand t of SO_2. The average SO_2 generation rate (α) is 11.9 kg/t (Figure 7).

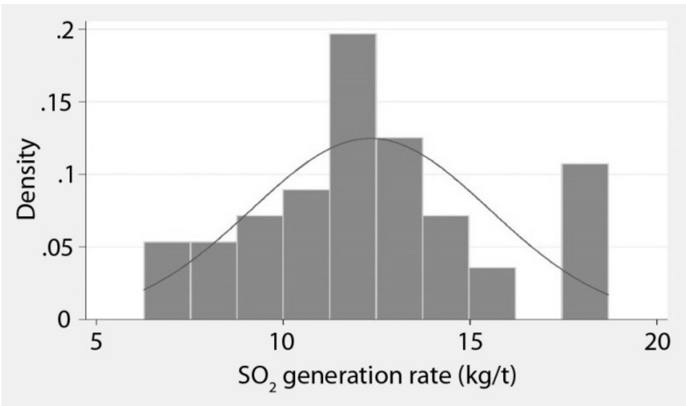

Figure 7. Distribution of SO_2 generation rate (α)

Finally, 445.5 thousand t of SO_2 was abated and another 526.0 thousand t were discharged into the environment. The reduction rate was 46.3%. Forty-five (45) power plants spent CNY 1291.4 million on pollution mitigation and the average SO_2 abatement costs were CNY 2.898/kg (Figure 8).

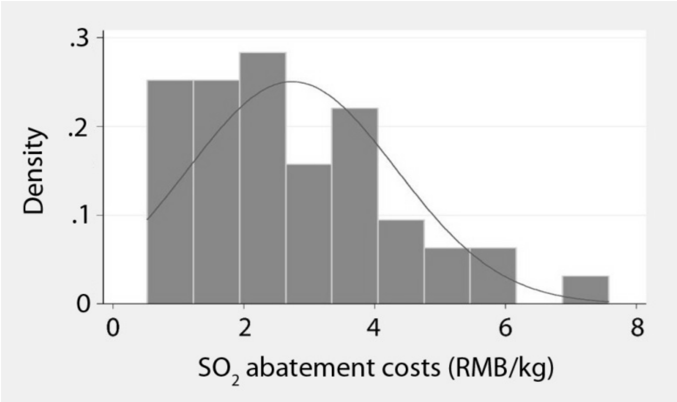

Figure 8. Distribution of SO_2 abatement costs

In this paper $c_i(r_i)$ is the emission abatement cost, for which $c_i'(r_i) > 0$ and $c_i''(r_i) \geq 0$. We have defined

$$c=\emptyset\alpha q\theta\kappa^{\frac{1}{1-\theta}} \quad \text{(Equation 19)}$$

We assume that all the power plants have the same value of κ and ∅ to estimate the value of κ. Take $R = \alpha q\theta$ as the emissions reduced by power plants, and $x = \frac{1}{1-\theta}$. Thus, we have the regression equation:

$$\ln c = \ln\emptyset + \ln R + x\ln\kappa + \varepsilon \quad \text{(Equation 20)}$$

Here, ε is error. Using the database of the 45 power plants, the regression results are shown in Table 4. The coefficient of x is the value of lnκ. So lnκ = 0.0565 and κ = 1.0581363.

Table 4. Regression results of emissions abatement costs

Source	SS	Df	MS		Number of obs.	45
Model	73.4143	2	36.7072		F(2, 42)	152.61
					Prob > F	0
Residual	10.1025	42	0.2405		R-squared	0.879
					Adj R-squared	0.8733
Total	83.5168	44	1.8981		Root MSE	0.49044
Lnc	Coef.	Std. Err.	t	P>t	[95% Conf.	Interval]
LnR	1.2232	.0936	13.07	0.0000	1.0343	1.4121
X	0.0565	.0213	2.66	0.0110	0.0136	0.0994
_cons	-3.0840	1.4619	-2.11	0.0410	-6.0346	-0.1337

Since α, q, θ can be obtained from the power plant database, we can have:

$$\emptyset = \frac{c}{\alpha q\theta K^{\frac{1}{1-\theta}}} \quad \text{(Equation 21)}$$

Using Equation 21, we can obtain the value of ∅ (Figure 9). ∅ is a constant in our model and it depends on a power plant's technology and equipment. In most of the power plants, ∅ is around CNY 2/kg. However, some old power plants have an extremely high value for ∅, which results in high average emission abatement costs.

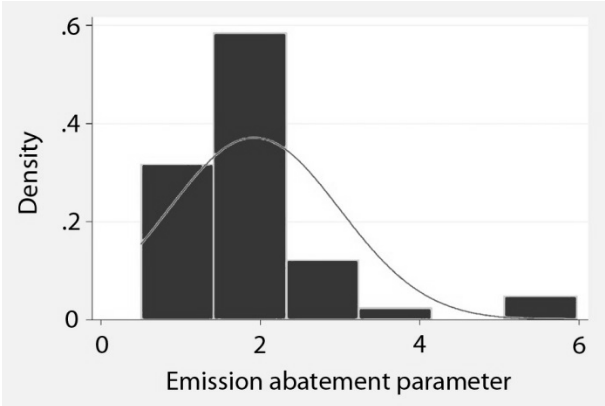

Figure 9. Distribution of the emission abatement parameter Ø

3.1.5 Electricity price and coal price

The electricity price is not decided by the market in China. China's electricity price is decided according to the "cost-plus pricing" principle, which is used to determine the electricity price based on direct costs, indirect costs, and fixed costs whether related to the production and sale of the product or service or not. These costs are converted to per-unit costs for the product and then a predetermined percentage of these costs are added to provide a profit margin. Using the "Notice of the National Development and Reform Commission about the electricity price of eastern China" (NDRC [2006]1230#) as guidance, Jiangsu Provincial Financial Bureau determined the price of electricity from the power plants in Jiangsu. The price of electricity from most power plants in Jiangsu is between CNY 0.38 and CNY 0.39/KW (Figure 10).

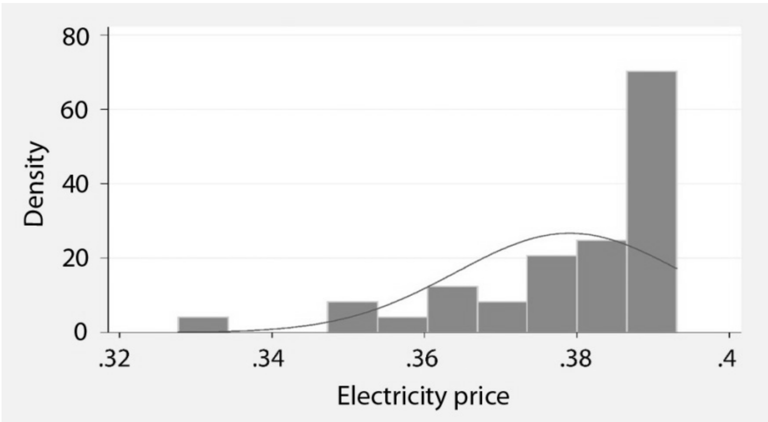

Figure 10. Price of electricity produced by power plants in Jiangsu

With the rapid economic growth in China since the economic reform in 1979, the nation recently experienced an overall energy shortage. In particular, the shortage was characterized by severe bottlenecks created by restricted electricity transmission capacity in the western regions (regions with abundant power resources) and faster growing energy demand in the eastern regions (regions with less abundant power resources). On the other hand, economists claim that most energy input sources are underpriced, causing resource distortions in the economy, with the possibility of unsustainable continuous growth, and accompanying environmental problems.

China has abundant supplies of coal and so relies heavily on it as the main energy input source across the country; the low price of coal is essential to the nation's economic growth. When referring to the price of coal in China, the current coal price and costs do not reflect the coal resource costs, coal mine retirement costs and environmental costs. Recently, the upgrade of resource protection, environmental protection and labor conditions have increased coal production costs and the price of coal. In addition, the tension between coal supply and demand makes for large fluctuations in its price (Figure 11).

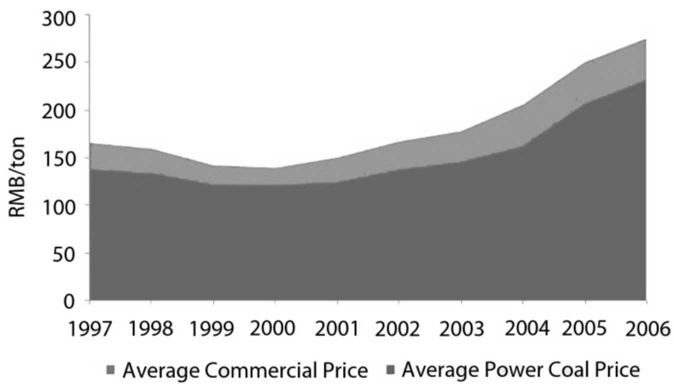

Figure 11. Coal price from 1997-2006

3.1.6 Summary

The summary of key variables is presented in Table 5.

Table 5. Summary of variables

Variable	Obs.	Mean	Std. Dev.	Min.	Max.	Reference
A_i	45	7064.489	4509.529	1609	23232	JSEPB 2002
c_i	45	49.30889	61.49958	0.8	299.4	Environmental Statistics System of Jiangsu
e_d	45	12365.37	15213.36	253	87425	
q_i	45	2366908	1603932	268000	7751678	
$g_i(q_i)$	45	5528	3654.32	600	17500	
P_e	45	0.3804711	0.0142959	0.3277	0.3931	JSFB 2006
P_c	-	592	-	-	-	Environmental Statistics System of Jiangsu
P_d	-	1.26	-	-	-	JSEPB *et al.* 2007
K	-	1.0581363	-	-	-	-
k	-	0.92011	-	-	-	
Φ	-	1.222	-	-	-	Environmental Statistics System of Jiangsu

3.2 Simulation Results of Single Jiangsu SO_2 Emissions Trading Market

To evaluate the proposed artificial market model and policy performance, we first examined the performance of a competitive emissions trading market and compared it to the "command and control" scenario, in which emissions trading is not allowed. The equilibrium price in the Jiangsu SO_2 emissions trading market is CNY 5.46/kg, and the marginal control costs are equated across all agents. The total emissions control cost decreased to CNY 3.85 E+09 when the market achieved equilibrium, thereby saving CNY 5.49E+08 (12.5%) of the total emissions control cost or increasing profits to CNY 5.49E+08 (1.2%) compared to the command and control scenario[2] (Figure 12).

In a completely competitive market, although the price at the beginning of emissions trading will be uncertain, the market price will converge to the equilibrium price. Such conclusions have been proved by many theoretical analyses (Stavins 1995). If other conditions are not changed, all the power plants will trade permits at the equilibrium price.

[2] In which, emissions trading is not allowed and all power plants should not exceed their permit cap.

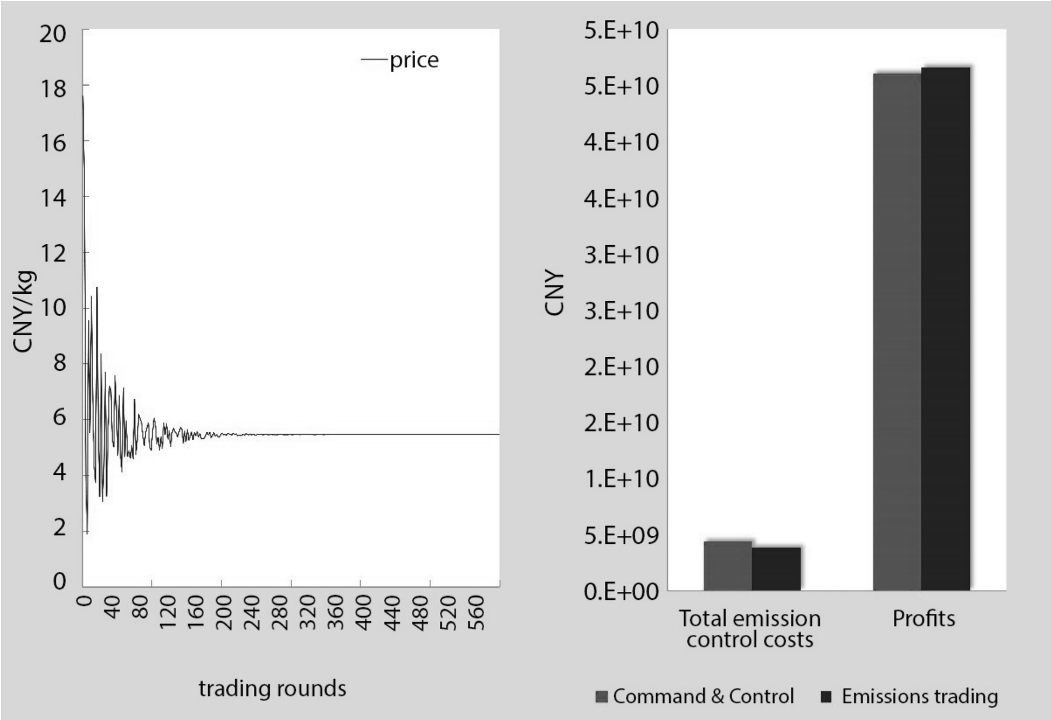

Figure 12. Market performance of Jiangsu emissions trading market compared to the command and control scenario

3.3 Simulation Results of Emissions Trading Market under Policy Conflicts

This research chose four key existing environmental policies in China to examine their impacts on the performance of emissions trading policy. According to previous analysis, we will combine the following four policy variables into the emissions trading model:

1. ***Regional total pollution control policy.*** Every region (city) in China has a regional cap (RC_j) for SO_2 emissions. So the total emissions discharge of all power plants in a region *j* should be no more than the regional cap (RC_j).

$$\sum_{i=1}^{m} a_{it} (1 - \theta_{it}) q_{it} \leq RC_j \qquad \text{(Equation 22)}$$

2. ***Pollution reduction requirement of the 11th Five-Year Plan.*** According to the pollution reduction requirement in the 11th Five-Year Plan, every power plant in China should abate more than 85% SO_2. Thus we have:

$$0.85 \leq \theta_{it} \leq 1 \qquad \text{(Equation 23)}$$

3. ***Electricity Generation Right.*** Power plants in China also have to take into account the restrictions imposed by the Electricity Generation Right, according to which power plants cannot generate more electricity than EGR_i.

$$g_{it}(q_{it}) \leq EGR_i \qquad \text{(Equation 24)}$$

4. ***Pollution discharge levy.*** In order to establish whether the current emissions discharge fee has an impact on the emissions trading market, we decline $p_d = 1.26$.

A step-by-step process was carried out to examine the impact of policy conflict. Thus, we developed another five models (model-1 to model-5) and compared them to model-0, which did not take policy conflicts into conderation (Table 6).

Table 6. Summary of emissions trading models

Model	Regional total pollution control policy $\sum_{i=1}^{m} a_{it}(1-\theta_{it})q_{it} \leqslant RC_j$	Pollution discharge standard $0.85 \leqslant \theta_{it} \leqslant 1$	Electricity Generation Right $g_{it}(q_{it}) \leqslant EGR_i$	Pollution discharge levy $P_d = 1.26$
Model-0				
Model-1	√			
Model-2		√		
Model-3			√	
Model-4				√
Model-5	√	√	√	√

Figure 13 shows the amount of emissions traded on Jiangsu's SO_2 emissions trading market. Policy conflicts or constraints reduce the amount of emissions traded and stand in the way of this market achieving global optimization alongside the pollution discharge levy. When comparing the four policy conflict scenarios, the regional total pollution control target had the most significant impact on the performance of the emissions trading market, reducing the amount of emissions traded by 33.25%. At the opposite end of this spectrum, the pollution discharge levy has little impact on the amount of emissions traded. If all four policy conflicts are factored into the emissions trading market, the amount of emissions traded would reduce to 7,534 t of SO_2, which is 10.9% of model-0.

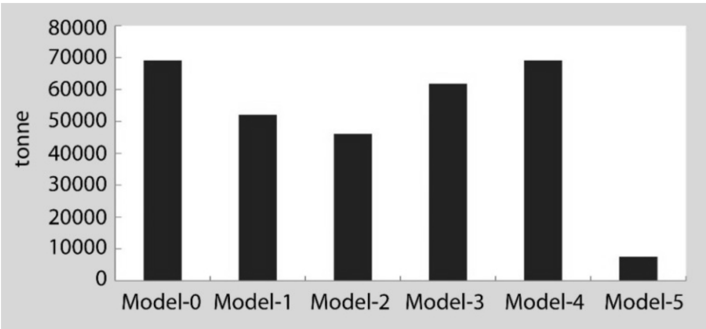

Figure 13. Amount of emissions traded via the Jiangsu SO_2 emissions trading market

Restrictions on emissions trading reduce the cost savings of the Jiangsu SO_2 emissions trading market. Figure 14 presents the total emissions control costs and cost savings of the Jiangsu SO_2 emissions trading market. Both the pollution discharge standard and the pollution discharge levy would increase the total pollution control costs, while the Electricity Generation Right decreases it. The regional total pollution control policy had the most significant impact on the cost savings of the Jiangsu SO_2 emissions trading market, reducing the cost saving of model-0 by 42.3%. Taking all four policy conflicts into account in the emissions trading market, would give a cost saving of CNY 1.55E+08, which is only 3.79% of the total emission control costs.

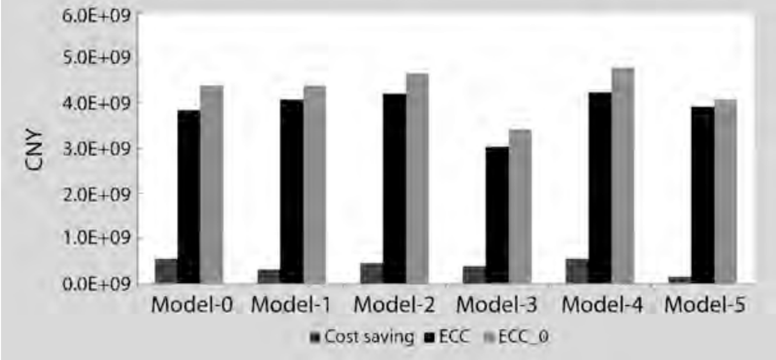

Figure 14. Total emissions control costs and cost savings of the Jiangsu SO_2 emissions trading market

3.4 Discussion

3.4.1 Regional total pollution control policy

Without the restraint of the regional total pollution control policy, power plants can trade across regions. We first modeled an emissions trading market which allows trading across regions. Figure 15 shows the flow of permits across the region of the Jiangsu SO_2 emissions trading market. Yangzhou and Nanjing are two main cities that purchase permits from other cities, while Taizhou and Nantong export permits. If pollution trading across regions is not allowed, the Jiangsu emissions trading market would be divided into 13 emissions trading markets. An emissions trading market that achieves local optimization cannot achieve global (Jiangsu provincial) optimization. Different regions (cities) in the Jiangsu SO_2 emissions trading market will have differnet marginal profits or marginal pollution abatement costs. Thus, the size of the market is important for emissions trading policy.

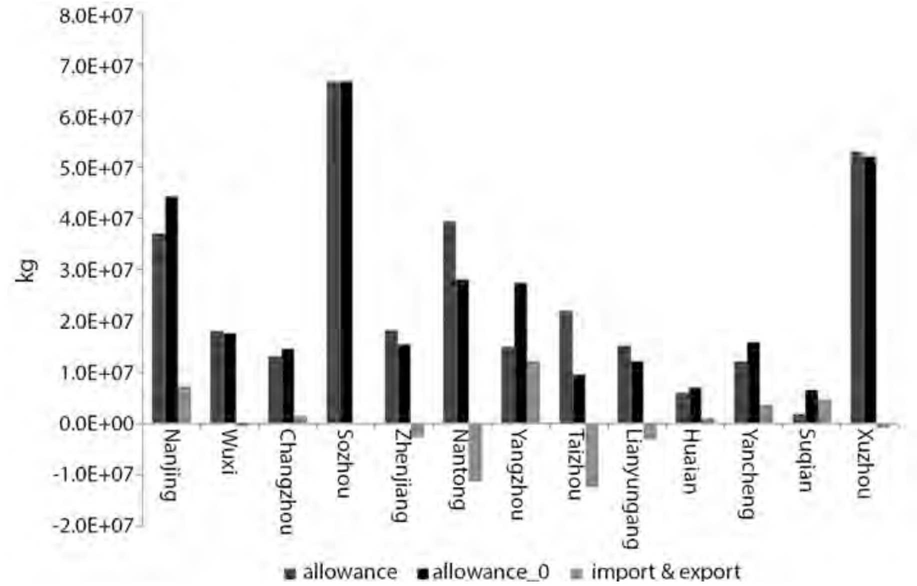

Figure 15. Flow of regional permits, Jiangsu SO_2 emissions trading market

3.4.2 Pollution discharge standard

The required SO_2 discharge standard also impacts on power plants with high emissions abatement costs; they cannot buy permits instead of reducing pollution by themselves. We examined the results of model-0 and the distribution of the SO_2 removal rate (θ) is illustrated in Figure 16. More than half (67%) of the power plants' SO_2 removal rate were lower than 85%. While we took the SO_2 discharge standard into the emissions trading model (model-2), all of the SO_2 removal rate was greater than or equal to 85%. Increased SO_2 removal rate will reduce the demand for permits, as well as the emissions trading amount. The emissions trading market cannot achieve equilibrium status therefore the total pollution control costs of model-2 will be higher than that of model-0.

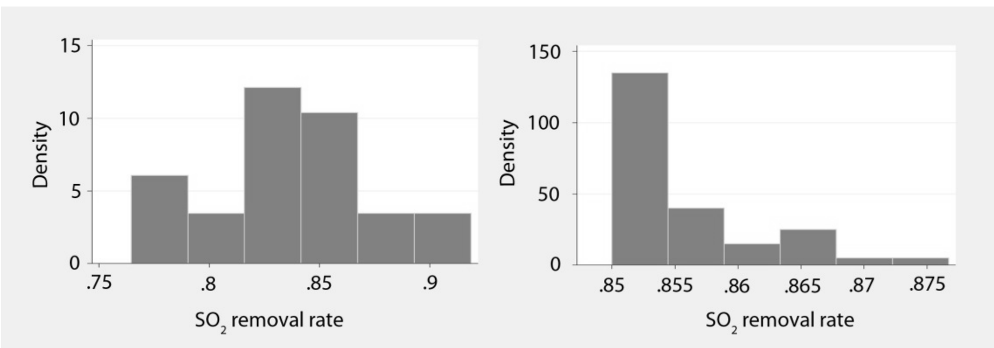

Figure 16. Distribution of SO_2 removal rate (θ) in model-0 (left) and model-2 (right)

3.4.3 Electricity Generation Right

In this research, power plants can adjust the amount of electricity they generate in order to reduce pollution. On the other hand, if power plants' marginal profit is higher than the market price, they could increase electricity generation to obtain more profits. However, if we take the Electricity Generation Right into consideration, every power plant would be restricted by it; they cannot generate more electricity than they have a right to.

Figure 17 shows the final electricity generation in model-0 and model-3. The results show that most power plants' final electricity generation in model-3 was lower than that in model-0. The lower motivation to generate electricity would decrease the demand for permits, which would reduce the emissions trading amount, as well as the total pollution cost saving.

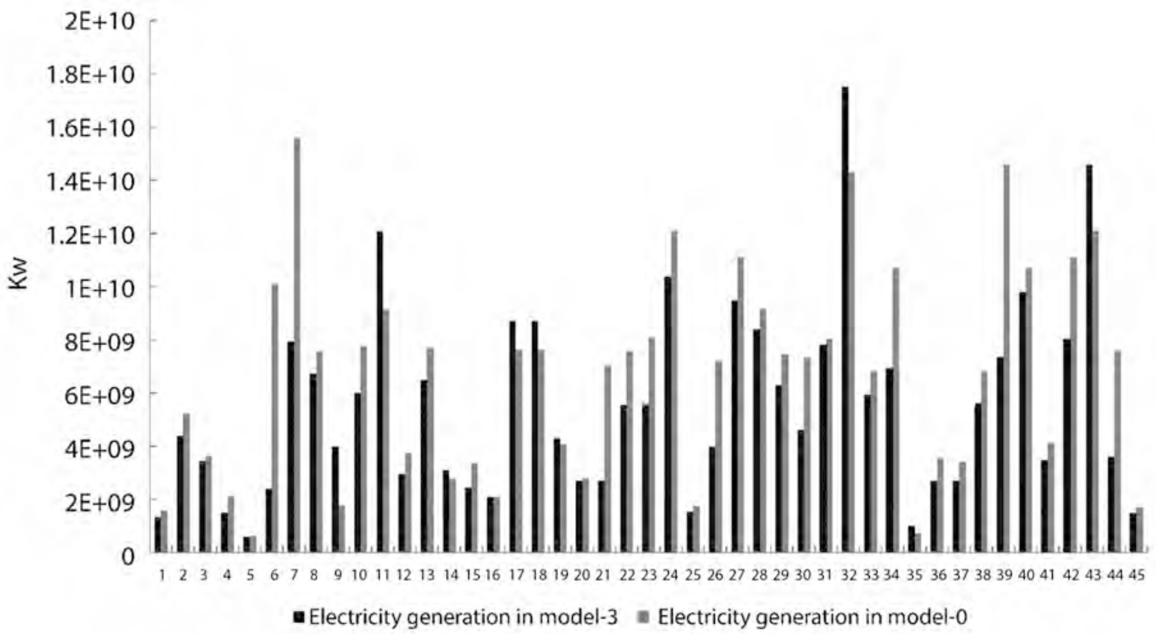

Figure 17. Electricity generation in model-0 compared to electricity generation in model-3

3.4.4 Pollution discharge levy

The pollution discharge fee increases the costs of a power plant and reduces the motivation to generate electricity. When we change the emissions discharge fee/tax to CNY 0/kg and CNY 5.67/kg, it increases the total pollution control cost significantly. In addition, increasing the emissions discharge fee would also decrease the market price when the emissions discharge fee is CNY 5.67/kg – the permit market market price would trend to 0 and no trading would take place (Figure 18). When the emissions discharge fee is at a low level, it would not affect the emissions trading amount and cost savings, and the only function of the emissions discharge fee/tax is to transfer profits from the power plants to the government. However, when the emissions discharge fee is at a high level, it reduces both the market price and the cost saving of the Jiangsu SO_2 emissions trading market.

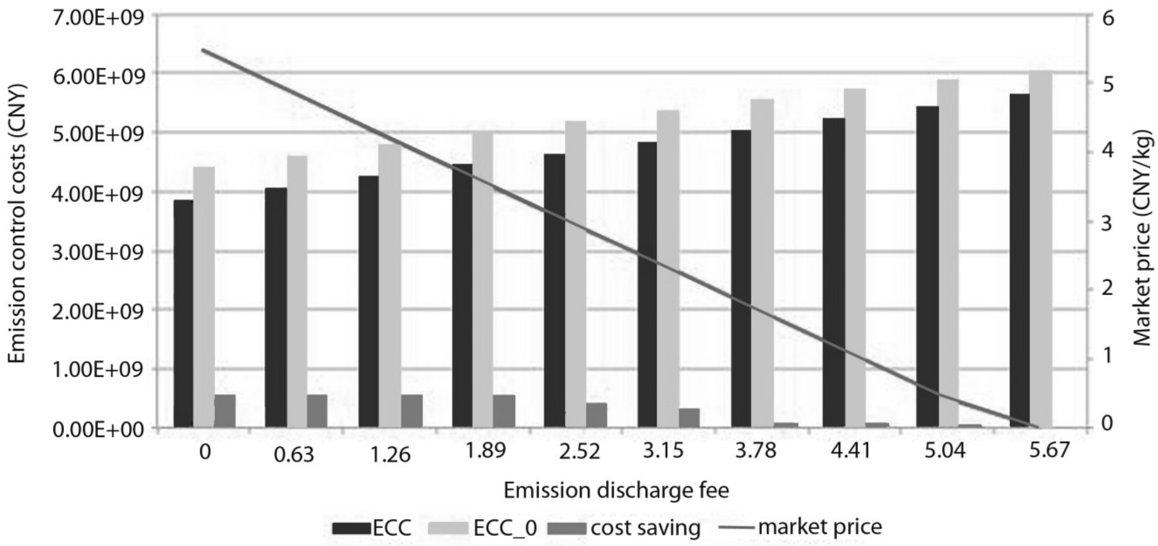

Figure 18. Emission control costs and market price under different emissions discharge fee scenarios

4.0 CONCLUSIONS

Not only the policy design, but also the existing environmental regulation system will influence the performance of an emissions trading market. This research put the emissions trading policy in amongst the whole environmental regulation system and identified the main policy conflicts between an emissions trading policy and other existing environmental policies. Taking the Jiangsu SO_2 emissions trading market as a case study, this research developed an agent-based model of emissions trading. Combining the policy conflicts with the agent-based model, the market performance of the Jiangsu SO_2 emissions trading market was examined.

Results showed that policy conflicts had a significant impact on the Jiangsu SO_2 emissions trading market, with the exception of the current level of the pollution discharge fee. The regional total pollution control policy had the most significant impact on market performance. Taking all four policy conflicts into consideration, the total pollution control costs saved by the emissions trading market was limited (4.79%).

4.1 Policy Implications

According to findings of this research, China should develop emissions trading programs more carefully. The design of emissions trading policy should pay attention to existing environmental regulation, which was designed without taking emissions trading into account. Our research has led to the following policy suggestions:

- Since the size of the market has a significant impact on the performance of an emissions trading market, a large-scale market should be designed in China. According to China's province-based total pollution control mechanism and regional pollution control strategies, a province-level emissions trading market or a regional-level emissions trading market (such as Yantize River Delta) is more suitable for implementing SO_2 emissions trading policy.

- Unlike the total pollution reduction, the pollution discharge standard is set according to health impact and available techonology, among others. Thus, the motivation of power plants to trade emission permits depends on the profits in electricity generation. The Electricity Generation Right inhibits power plants with a high marginal profit from buying SO_2 permits from power plants with low marginal profits. In light of this, a generation right trading system for power plants is also suggested (Wang and Zhang 2005).

- The emissions discharge fee/tax has existed as an alternative environmental economic instrument in China since 1982. This price-based approach (tax) and quantity-based approach (emissions trading) could achieve equivalent welfare consequences under perfect information conditions. However, uncertainty regarding compliance costs causes the equivalent price and quantity controls to behave differently, and leads to divergent welfare consequences (Weitzman 1974). A hybrid policy in place of pure price or quantity controls is considered more efficient as a "safety valve" (Jacoby and Ellerman 2004; Pizer 2002; Stranlund 2009).

  Power plants in Jiangsu should also pay the emissions discharge fee/tax. Our simulation results show that an increase in the emissions discharge fee/tax depresses the emissions permit price. The current emissions discharge fee/tax does not affect the emissions trading amount and total emission control costs, but transfers some profits from power plants to government. However, superfluous environmental regulations will hinder the technology innovation of power plants (Oates *et al.* 1993) and increase administrative costs (Ellerman *et al.* 1997). Thus, the design of an emissions trading policy should be combined with an emissions discharge tax/fee policy, and a low-level emissions discharge tax/fee is recommended for the SO_2 emissions trading policy in Jiangsu.

4.2 Future Research

In addition, this research looked at four existing environmental policies and their effect on the Jiangsu SO_2 emissions trading market. We achieved this via interviews we conducted with staff at the featured power plants in Jiangsu Province. However, the behavior of the power plants in the emissions trading market is very complex and will be impacted further by other environmental policies. Further research should take all of these related policies into consideration.

4.3 Dissemination

China's central government and Jiangsu Province plan to issue new emissions trading regulation during the 12th Five-Year Plan period. So that our research results can influence this new policy design, we held two workshops on SO_2 emissions trading in Nanjing. The Jiangsu Environmental Protection Department gave a positive evaluation of our research results. However, the Electricity Generation Right policy and pollution discharge fee policy cannot be changed by provincial environmental protection departments. In light of this, we also plan to submit our research results and policy suggestions to the Ministry of Environmental Protection.

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APPENDICES

Appendix 1. Marginal profits

The representative firms' optimization problem is

$$max\ \pi = Gq^k p_e - \varphi p_c q - \emptyset \alpha q \theta \kappa^{\frac{1}{1-\theta}} - p_d \alpha q(1 - \theta) \quad \text{(Equation A.1)}$$

$$subject\ to{:}\ A - \alpha q(1 - \theta) \geq 0 \quad \text{(Equation A.2)}$$

We define the Lagrangian expression as

$$L = Gq^k p_e - \varphi p_c q - \emptyset \alpha q \theta \kappa^{\frac{1}{1-\theta}} - p_d \alpha q(1 - \theta) + \lambda(A - \alpha q(1 - \theta)) \quad \text{(Equation A.3)}$$

The necessary first-order conditions determining a maximum at $(q^*, \theta^*, \lambda^*)$ are

$$Gkq^{*k-1} p_e - \varphi p_c - \emptyset \alpha \theta^* \kappa^{\frac{1}{1-\theta^*}} - p_d \alpha(1-\theta^*) - \lambda^* \alpha(1-\theta^*) = 0 \quad \text{(Equation A.4)}$$

$$-\emptyset \alpha q^* \kappa^{\frac{1}{1-\theta^*}} \left(1 + \frac{\theta^* \ln\kappa}{\left(1-\theta^*\right)^2}\right) + p_d \alpha q^* + \lambda^* \alpha q^*) = 0 \quad \text{(Equation A.5)}$$

Solving Eq.(A.5), we have

$$\lambda^* = \emptyset \kappa^{\frac{1}{1-\theta}} \left(1 + \frac{\theta^* \ln\kappa}{(1-\theta)^2}\right) - p_d \quad \text{(Equation A.6)}$$

Here, λ^* is the Lagrangian multiplier and represents the marginal profits of a unit permit.

Appendix 2. Learning strategies

At a given time t, an individual ZIP agent (denoted by subscript i) calculates the shout price $p_i(t)$ from price $\lambda_{i,j}$ using the agent's real valued profit margin $\mu_i(t)$ according to

$$p_i(t) = \lambda_{i,j}(1 + \mu_i(t)) \quad \text{(Equation B.1)}$$

This implies that a seller's margin is raised by increasing μ_i and lowered by decreasing μ_i with the constraint that $\mu_i(t) \in [-1,0]:\forall t$. The aim is that the value of μ_i for each trader should alter dynamically in response to the actions of other traders in the market, increasing or decreasing to maintain a competitive match between that trader's shout price and the shouts of the other traders. According to the Widrow-Hoff's "delta rule"(Zhan and Zhan 2008), we have

$$Y(t + 1) = Y(t) + \Delta(t) \quad \text{(Equation B.2)}$$

where $Y(t)$ is the *actual output* at time t, $Y(t+1)$ is the actual output in the next time step; and $\Delta(t)$ is the change in output, determined by the product of the learning rate coefficient V and the difference between $Y(t)$ and the desired output at time t, denoted by $D(t)$

$$\Delta(t) = v(D(t) - Y(t)) \quad \text{(Equation B.3)}$$

The following adaptation method is employed by the ZIP traders. When a trader is required to increase or decrease their profit margin, a "target price" (denoted $\tau_i(t)$) will be calculated for each trader, and the Widrow-Hoff rule will then be applied to make the trader's shout price in the next time step ($p_i(t+1)$) closer to the target price $\tau_i(t)$. Because the shout price is calculated using the (fixed) limit price $\lambda_{i,j}$ and (variable) profit margin μ_i, it is necessary to rearrange Eq.(B.1) to give an updated rule for the profit margin μ_i in the transition from time t to $t+1$:

$$\mu_i(t + 1) = (p_i(t) + \Delta_i(t))/\lambda_{i,j} - 1 \quad \text{(Equation B.4)}$$

where $\Delta_i(t)$ is the Widrow-Hoff delta value calculated using the individual trader's learning rate β_i:

$$\Delta_i(t) = v_i(\tau_i(t) - p_i(t)) \quad \text{(Equation B.5)}$$

All that remains is to determine how to set the target price $\tau_i(t)$. While a simple method would be to set the target price equal to the price of the last shout (i.e., $\tau_i(t) = q(t)$), this presents a significant problem. When the last shout price is very close to, or equal to, the trader's current shout price (i.e., $p(t) \approx q(t)$), the value of $\Delta_i(t)$ given by Eq.(B.5) will be very small, or zero. Thus, traders who would have shouted prices close to $q(t)$ are likely to make negligible alterations to their profit margins, and so will shout very similar prices when next given the opportunity.

There are many ways in which the target price $\tau_i(t)$ could be determined. In our model, the target price is generated using a stochastic function of the shout price $q(t)$:

$$\tau_i(t) = H_i(t)q(t) + Y_i(t) \quad \text{(Equation B.6)}$$

where H_i is a randomly generated coefficient that sets the target price *relative* to the price $q(t)$ of the last shout price, and $Y_i(t)$ is a (small) random *absolute* price alteration (or perturbation). When the intention is to increase the dealer's shout price, $H_i > 1.0$ and $Y_i > 0.0$; when the intention is to decrease it, $0.0<H_i < 1.0$ and $Y_i < 0.0$. In our model, we set H_i to be uniformly distributed over the range [1.0,1.05] for price increases and over [0.95,1.0] for price decreases, giving relative rises or falls of up to 5%, and Y_i is uniformly distributed over [0.0,0.1] for increases and [-0.1,0.0] for decreases. The value of each trader's learning rate v_i is randomly generated when the trader is initialized, using values uniformly distributed over [0.1,0.5].

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