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Research article

An agent-based model for an air emissions cap and trade program: A case study in Taiwan

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ABSTRACT

To determine the actual status of individuals in a system and the trading interaction between polluters, this study uses an agent-based model to set up a virtual world that represents the Kaohsiung and Pingtung regions in Taiwan, which are under the country's air emissions cap and trade program. The model can simulate each controlled industry's dynamic behavioral condition with the bottom-up method and can investigate the impact of the program and determine the industry's emissions reduction and trading condition. This model can be used elastically to predict the impact of the trading market through adjusting different settings of the program rules or combining the settings with other measures.

The simulation results show that the emissions trading market has an oversupply, but we find that the market trading amounts are low. Additionally, we find that increasing the air pollution fee and offset rate restrains the agents' trading decision, according to the simulation results of each scenario. In particular, NO_x and SO_x trading amounts are easily impacted by the pollution fee, reduction rate, and offset rate. Also, the more transparent the market, the more it can help polluters trade. Therefore, if authorities want to intervene in the emissions trading market, they must be careful in adjusting the air pollution fee and program rules; otherwise, the trading market system cannot work effectively. We also suggest setting up a trading platform to help the dealers negotiate successfully.

1. Introduction

According to the “Air Pollution Control Act” established by the Taiwan Environmental Protection Administration (Taiwan EPA), when the air emissions cap and trade program is implemented, an existing stationary pollution source must apply to the local environmental authority to confirm its actual pollutant emission amounts, based on which the authority will set reduction goals; the polluter must then make the reductions in accordance with the goals and deadlines that are outlined by the Taiwan EPA's air quality requirements. If the pollution source's actual emissions reduction quantities are greater than the designated reduction quantities, it may bank, offset, or trade the difference with the authorization of the local environmental authority (Taiwan EPA, 2012a).

Air emissions cap and trade policies have been in place in the United States for quite some time; these policies include RECLAIM (South Coast Air Quality Management District, 1994), U.S. EPA Acid Rain Program (U.S. EPA, 1995), NO_x Budget Trading Program (U.S. EPA, 1999), New Source Review (NSR) (U.S. EPA, 2002), and Clean Air Interstate Rule (CAIR) (U.S. EPA, 2004). The policies have also been applied to broadly manage different air pollutants, with remarkable results. They can be implemented in conjunction with a trading system to induce pollution sources to reduce emissions based on cost-benefit analysis and to ultimately improve air quality.

The Kaohsiung and Pingtung regions (the most southern counties) of Taiwan have yet to meet the air quality standards for PM_{10} (particulate matter 10 μm or less in diameter) and ozone (O_3) after a long-term implementation of measures, including emission standards, emission permits, reporting and monitoring management, and air pollution fees. These regions began the air emissions cap and trade program to improve air quality in June 2015 (Taiwan EPA, 2015). This is the first time that such a program was implemented in Taiwan, so our aim is to establish a model that could determine trading and reduction status in order to evaluate the program's impact. Besides, we also want to investigate the effect of other measures that interact with the program.

Many previous studies on emissions cap systems mostly use top-down mathematical methods to build models. For example, Montgomery (1972) studied the trading system model that

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considers the minimization of the total pollution controlling cost and then used the model to investigate the optimal emissions trading solution. This method has been widely used in advanced studies, such as in discussions of emission allowance allocation methods (Hahn, 1984; Rose et al., 1998; Cramton and Kerr, 2002). Mao et al. (1999) used the mathematical linear programming method to study how the steel industries choose the optimization plans for particle control equipment under the limitations of the air emissions cap and revealed the quantitative relationship between total investment costs and total emission amounts. Further, Al-Ali et al. (2008) built a mathematical programming model that can select the best pollution (sulfur oxides (SO_x) and nitrogen oxides (NO_x)) and greenhouse gas (carbon dioxide (CO_2)) controlling strategies to achieve reduction goals, through a case study of the refinery industry. However, these top-down methods need to make strong assumptions to simplify the studied industries' heterogeneity, and assume that these industries have all the relevant information about each other's characteristics and behaviors. Therefore, these methods cannot reflect the real behavioral change as an impact of policy (Rothkopf, 1999). Further, they ignore the decision making and interaction between each player in simulating the equilibrium solution (optimality analysis), and they cannot simulate the dynamic trading process (Richstein et al., 2014). In reality, the trading market is determined by dealers and belongs to a dynamic and complicated system (Weidlich and Veit, 2008).

Considering the complicated system of the air emissions cap and trade program, we wanted to use the bottom-up approach to build a model that can take each controlled industry's behavioral decision into consideration. The agent-based model (ABM) is one appealing new methodology that has the potential to treat these problems (Gulden, 2013), and it has been applied for trading systems, such as for the electricity market (Praça et al., 2005; Veit et al., 2009) and tradable discharge permit system (Zhang et al., 2013). These studies showed that the ABM offers elastic ways to investigate results of different scenarios according to the setting of different rules of dealers. For example, the ABM was used to simulate the trading result of alternative sulfur dioxide (SO_2) allowance allocation methods (Liu et al., 2012) and the influence of taxes or fees on the SO_2 trading system (Zhang et al., 2010). Besides, the ABM can study how the CO_2 emission trading market interacts with the commodity market (Tang et al., 2015) or electric supply market effect (Wang et al., 2009).

Unlike the traditional top-down method, the ABM stresses that each individual has its own decision and interaction process (Macal and North, 2010; Muaz and Hussain, 2011). Further, the ABM for the trading market emphasizes the behavioral rules between dealers or participants under the trading system, and the macroscopic simulation result is determined by these microscopic individual interactions (Huang et al., 2015).

Thus, this study aims to develop an ABM not only to describe the relationships in a complex system, but also to simulate their trading behaviors in an artificial system. This approach can determine each industry's emissions reduction and trade condition to investigate the impact of the program. The model is used to assess other measures or conditions, such as economy-interfering measures, adjustment of program rules' settings, market transparency, and the effect on the controlled industries' decisions. Compared with the previous studies that focused on the simulation of the trading market, this study simulates the whole system and the procedures involved. The ABM is considered suitable for studying the impact of the air emissions cap and trade program in Taiwan and can contribute to establishing new ways to investigate the management policy for air quality protection.

2. Data sources and methodology

2.1. Case study

This study chose the Kaohsiung and Pingtung regions, located in the south of Taiwan, for the case study. The rules of the air emissions cap and trade program in Taiwan are similar to those of the NSR and RECLAIM. They stress that the polluters would either need to reduce their emissions or obtain offset amounts depending on whether their emissions are greater than or less than their emission benchmark; this approach is unlike the emissions credit allocation by the authority (Taiwan EPA, 2012b).

Several important concepts in the rules of this program are described below:

(1) Emission in baseline year: The controlled industry's annual emission benchmark would be chosen by the industry itself from any of the annual emissions in the previous seven years. The industry must apply to the local environmental authority for review.
(2) Reduction goal: The controlled industry must reduce the emission of each pollutant—PM, SO_x, NO_x, and volatile organic compounds (VOCs)—by 5% compared to the emission of the baseline year, within three years.
(3) Offset permits: After the controlled industry modifies its control technology, it could apply offset permits for each pollutant for which the current emission amount is less than the emission of the baseline year.
(4) Offset rules: The buyer must buy 1.2 times the reduction amount to offset, and the offset permits bought can be used only for a specific pollutant (e.g., offset permits from PM reduction can only be used for offsetting PM).

2.2. Study methods

First, this study identifies the model's boundaries and agents. Second, it collects relevant data to establish the behavior rules and settings for the model framework. Third, it uses the model to simulate each agent's emissions reduction, process of negotiation, and trading results. Finally, the study sets different scenarios to assess the impact of the program's interaction with other measures.

2.2.1. Model tools

This study uses the NetLogo tool (Version 5.1.0) to construct the model. This tool, which was developed by Northwestern University (Wilensky, 1999) in the United States, offers an interface for inputting parameter values and enables viewing images of the simulation process and the simulation results. In addition, it is an open-source software that researchers can use to design their own model system, and some studies of the agent-based method (Nikolic et al., 2013; Bichraoui et al., 2013; Liu, 2013) have used this tool to present their methods and results.

2.2.2. Agent-based model

The ABM framework includes model setting. Using the data and program rule settings (see Fig. 1), we introduce the model design in the following:

2.2.2.1. Model boundaries and agent settings. The boundary of this study's system includes the Kaohsiung and Pingtung regions of Taiwan. There are 557 industries that are managed by the program, including manufacturing industries (96%), waste treatment and recycling industries (3%), hospitals (0.3%), and electricity suppliers (0.7%), and we set these industries as agents. The simulated