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Carbon emissions trading scheme exploration in China: A multi-agent-based model

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HIGHLIGHTS

- A multi-agent-based model is proposed for carbon emissions trading (CET) in China.
- Three agents are included: government, firms in different sectors and households.
- The impacts of CET on the economy and environment in China are analyzed.
- Different CET designs are simulated to find an appropriate policy for China.
- Results confirm the effectiveness of the model and give helpful insights into CET design.

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ABSTRACT

To develop a low-carbon economy, China launched seven pilot programs for carbon emissions trading (CET) in 2011 and plans to establish a nationwide CET mechanism in 2015. This paper formulated a multi-agent-based model to investigate the impacts of different CET designs in order to find the most appropriate one for China. The proposed bottom-up model includes all main economic agents in a general equilibrium framework. The simulation results indicate that (1) CET would effectively reduce carbon emissions, with a certain negative impact on the economy, (2) as for allowance allocation, the grandfathering rule is relatively moderate, while the benchmarking rule is more aggressive, (3) as for the carbon price, when the price level in the secondary CET market is regulated to be around RMB 40 per metric ton, a satisfactory emission mitigation effect can be obtained, (4) the penalty rate is suggested to be carefully designed to balance the economy development and mitigation effect, and (5) subsidy policy for energy technology improvement can effectively reduce carbon emissions without an additional negative impact on the economy. The results also indicate that the proposed novel model is a promising tool for CET policy making and analyses.

1. Introduction

In recent decades, coupled with economic development, the increase in carbon emissions has become the dominant contributor to the greenhouse effect and global climate change (Liu, 2013). Since 1979, a group of international organizations (e.g., IPCC, UNFCC, and APPCDC) have been created to work on carbon concentration reduction. Given such circumstances, policy makers, managers and academic scholars are trying to find effective policies to reduce carbon emissions (Duan and Hu, 2014). Amongst the various measures, the carbon emissions trading (CET) system has been widely considered as one of the most effective tools in curbing carbon emissions since it was first implemented in the EU (Dormady, 2014). As opposed to other mitigation tools, such as the carbon tax (known as a price instrument) which directly imposes an extra cost on emitters, CET (known as a quantity instrument) is actually a governmental policy-driven tool and tends to control emissions in a flexible way through market mechanisms rather than through compulsory regulation, which can effectively stimulate technology innovation for carbon mitigation (Gong and Zhou, 2013).

China, as one of the largest carbon emitters, has promised to lower the carbon intensity in the country by 40–45% of that in 2005 by 2020. To accomplish such a goal, China has launched seven pilot CET programs in 2011 and plans to establish a nationwide mechanism in 2015. Nevertheless, the market designs of

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the EU and other emissions trading schemes may not be suitable for China (Raufer and Li, 2009). With no uniform CET scheme design in place in China, two important questions arise concerning the impact of CET and the most effective CET design. In general, CET will inevitably affect China's economy by increasing production costs in terms of the carbon credit payment and technology improvement investment. However, a carefully designed CET scheme, involving the allowance allocation rule, carbon price, penalty policy and subsidy policy, might be helpful to both alleviate the economic loss and effectively reduce carbon emissions (Cheng and Zhang, 2011). Therefore, this paper attempts to investigate the potential impacts of different CET schemes on China and to search for the most appropriate CET scheme for China.

The existing studies on the impact and effectiveness of the CET system fall into three categories: firms, sectors and the overall economy. For firms, the relative studies have mainly focused on the optimal decision making under CET policy by using optimization programming models, including production planning, carbon emissions determination, carbon credit transactions and energy technology selection. For example, Gong and Zhou (2013) developed a dynamic production model to find optimal strategies for emissions trading, technology selection, and production under various CET schemes. Rong and Lahdelma (2007) proposed a multi-period stochastic optimization model to study a CO_2 emissions trading plan for a combined heat and power producer. Li et al. (2013) proposed a dynamic decision-making model to investigate the impacts of CET on the generation of company decisions in a multi-market environment. Li et al. (2014) developed an integrated optimization model for planning emissions trading and clean-energy development under uncertainty.

As for the sectoral impact, recent studies have especially focused on the energy-intensive sectors and energy sectors. For example, Lee et al. (2008) compared the impacts of carbon taxation and CET on five petrochemical-related industries based on a fuzzy goal programming model and suggested that a combined policy involving CET is friendlier to sectoral GDP than a single carbon tax policy. Cong and Wei (2010) studied the potential impact of CET on China's power sector based on an agent-based model (ABM). Zhao et al. (2010) proposed a nonlinear complementarity model to analyse the efficiency of different allowance allocation mechanisms in the electric power markets. Anger (2010) investigated the impact of the European Emission Trading Scheme on the aviation industry.

Regarding the overall impact on a national level, various simulation models, such as the computable general equilibrium (CGE) model, as well as optimal programming models have been employed. For simulation models, Abrell (2010) proposed a static multi-region CGE model to analyse the efficiency of CET and found that CET considering emissions in transportation would be superior to a closed CET or a tax-based approach in terms of welfare. Similarly, Hermeling et al. (2013) proposed a CGE model for the CET of the EU 2020 targets. Farrahi Moghaddam et al. (2013) analysed the impact of a border carbon tax (BCT) and a global emissions trading scheme (ETS) on global emissions reduction in terms of a modified greenhouse gas intensity indicator. For optimization programming models, Zhou et al. (2013) studied the economic performance of an interprovincial emission reduction quota trading scheme in China.

According to the extant literature, we have found that the existing numerical models were either limited to certain agents in CET-related sectors while ignoring the interactions with other agents or concentrated on macro-economy simulation while ignoring the microscopic activities of different agents (e.g., firms and households). For example, in the study of Chappin and Dijkema (2009) and Sichao et al. (2010), only the power sector was considered in the CET analysis; in Anger (2010), the aviation industry; and in Deja et al. (2010) and Szabó et al. (2006), the cement industry. However, because China plans to build a nationwide CET market, estimating the overall impact of different CET policies on the whole economy covering all main sectors is quite imperative to search for an appropriate CET scheme. Furthermore, in the study of Abrell (2010) and Hermeling et al. (2013), in which the nationwide and even global impacts of CET were estimated based on CGE, a bottom-up analysis on economic behaviors and interactions amongst various specific agents (i.e., firms and households) cannot be effectively captured. However, because the CET policy is a governmental policy-driven measure, the decisions of each heterogeneous firm (not only the representative firm in each sector via CGE) are extremely important for CET analysis.

Under such circumstances, this study tends to build a bottom-up model to study the impact of CET both on various economic agents from the microscopic perspective and on the whole economy and environment in China from the macroscopic perspective. First, because CET is a governmental policy-driven economic tool, we prefer to use a multi-agent-based model, the most typical bottom-up analysis technique, to effectively capture the activities and interactions amongst various specific agents rather than the CGE, a top-down model that can only reflect the activities at whole sector levels. Second, to explore the suitable CET schemes in China, different CET scheme scenarios are designed and simulated, with different allowance allocation rules, carbon price levels, penalty rates and subsidy rates.

In general, the main aim of this paper is to establish a multi-agent-based CET model to investigate the impact and effectiveness of CET on China and to search for an appropriate scheme for China. The rest of the paper is organized as follows. The proposed multi-agent-based CET model is formulated in Section 2. The simulation results are thoroughly analysed in Section 3. Section 4 discusses the validity of the proposed simulation model. Section 5 concludes the paper, provides some policy implications and notes areas of future research.

2. Methods

A multi-agent-based CET model is developed in this section to study the effectiveness of the CET policy and to find the most appropriate CET mechanism for China. First, the overall framework of the proposed model is formulated in Section 2.1. Second, the action rules of the economic agents and the markets are described in detail in Sections 2.2 and 2.3, respectively. Finally, Section 2.4 provides the data descriptions and model calibration.

2.1. Model framework

In the proposed model, three main types of agents are involved: firms, the government and households. Under the CET scheme, these agents would interact with each other through two main markets, i.e., the commodity market and the CET market. Fig. 1 illustrates the framework of our novel model for CET.

(1) The firms, as the CET-targeted agents, make their optimal decisions for production planning, energy technology selection, carbon credit transactions and commodity marketing planning by minimizing the losses caused by the CET policy.
(2) The government, as the CET designer and supervisor, verifies individual and total carbon emissions, allocates free carbon emissions quotas to related firms, imposes a penalty on noncompliance emissions (i.e., extra emissions beyond allowances), subsidizes green energy technology, and regulates the CET market. In addition, as an economic agent, the government gains fiscal revenue, consumes various commodities, and