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Impact of carbon allowance allocation on power industry in China's carbon trading market: Computable general equilibrium based analysis

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HIGHLIGHTS

- The mechanism on electricity sector can hardly affect GDP and CO_2 emissions.
- The impact of changing allocation on the aggregate economy is relatively small.
- The allocation mechanism on electricity based on emission intensity is suggested.

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ABSTRACT

Global warming has necessitated the quest for CO_2 mitigation globally. Emission Trading Scheme (ETS) is a market-oriented strategy which may be effective for CO_2 mitigation. This study establishes a Computable General Equilibrium (CGE) model to analyze the impact of different ETS quota allocation scheme on the electricity industry and determine the best choice of quota allocation scheme for the electricity industry in China. The research on China's carbon trading market may provide an important case for the global carbon trading market. The results show that different quota allocation schemes have impacts on electricity price, and there are some spillover effects to other industries. Higher Annual Decline Factor (ADF) will reduce carbon rights than lower ones. Changes in the quota allocation schemes of a single industry (electricity) can hardly affect aggregate GDP and CO_2 emissions. Moreover, ETS quota allocation scheme in the electricity sector based on historical emission intensity could have better performance in commodity price, electricity supply, ETS price, GDP and social welfare. Thus, this paper suggests that the best choice of ETS quota allocation scheme in the electricity sector is the scheme that is based on historical emission intensity which ADF is 0.

1. Introduction

The challenges of energy shortage, global warming and environmental degradation are becoming urgent global problems. With the increasing pace of industrialization in the world, excessive energy consumption is the main cause of carbon dioxide (CO_2) emission. To address these challenges, various measures for reducing carbon emissions are being studied and implemented [1]. Many emission reduction methods have been researched to energy saving and emission reduction [2]. For the aspects of policy tool, tax of carbon emission [3], forest carbon sinks [4], clean development mechanism [5] and Emission Trading Scheme (ETS) [6] are the usual methods for CO_2 mitigation. For instance, Fan et al. [7] tried to optimize the scheme of carbon trading in China based on a novel energy-saving and emission-reduction system with carbon price constraints and confirm that technical progress of energy saving and emission reduction is negatively correlated with carbon trading in the long run. Woo et al. [8] found that ETS program in California is effective in internalizing CO_2 emission costs of the in-state natural-gas-fired generation. For the aspects of technology, carbon capture and storage [9], electric vehicle [10], grid energy storage [11], and renewable energy [12]. For example, Tan et al. [13] analyzed policy impact of new energy vehicles promotion on air quality in Chinese cities. Fridahl [14] provided a unique intercontinental mapping of the prioritization of bioenergy with carbon capture and storage for the long term transition of the electricity supply sector. Requia et al. [15] found that across Canada the varying electricity

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generation profiles affected the potential reduction benefit in life-cycle CO_2 emissions. Sidhu et al. [16] explored and quantified the social costs and benefits of grid-scale electrical energy storage projects in Great Britain. Upton and Snyder [17] analyzed renewable portfolio standards and did not find evidence that renewable portfolio standards states have experienced increases in renewable energy generation relative to synthetic control. This paper will focus on ETS, which may be an effective method to CO_2 reduction. Some literature believes that carbon tax is easily influenced by government, the reduction efficiency may be lower and the loss of GDP may be higher compared with ETS [18]. However, others do not think so, such as Lu et al. [19]. This paper considers that carbon taxes are more likely to control enterprises' behavior through price, while carbon trading tends to control the outcome (CO_2 emissions) of enterprises' behavior through a trading market. The former may become a more effectively impactful tool whereas the latter may become an easier-to-use tool for controlling total emissions of the region. As such, the topic on how to improve the effectiveness of ETS is worth studying.

A lot of papers conduct researches on ETS. Yu et al. [20] proposed a method named a two-stage interval- probabilistic programming to better plan ETS market mechanism in Qingdao, China. Zhang et al. [21] simulated an integrated ETS with six major countries by applying CGE model and implementing different scenario analysis. While Pearse [22] had an interesting findings, he found that ETS cannot well address failures of coal governance in real world. Zhang et al. [23] using econometrics analysis (panel data) simulated the potential effect of ETS in China, such as GDP and carbon intensity. Creti and Joets [24] evaluated whether volatility of carbon price or price spikes are because of the bubble caused by speculation, and they found different episodes of price bubbles from 2005 to 2014 in EU-ETS. Liu et al. [25] proposed an integrated rule based on machine learning (genetic algorithms and particle swarm optimization) for better regulating futures market in EU-ETS. Balietti [26] studied on the relationship between the EUA price's volatility and the level of market activity during Phase I in EU-ETS. Based on four principles of equality, historical responsibility, capability, and future development opportunities, Wang et al. [27] proposed a new carbon allowance allocation mechanism. Chang et al. [28] estimated effects of economic welfare through interregional ETS market in China, and based on the Shapley value method they focused on a comprehensive solution of emissions reduction allocation. Jaskólski [29] analyzed the impact of EU-ETS for CO_2 emission trading mechanism combined with SO_2 and NO_x on electricity generation technology choice, and analyzed market allocation model of electricity industry in Polish. Tang et al. [30] studied the appropriate ETS policy design by developing a CGE model with an ETS block, which includes a carbon cap-and-trade, allowance allocation and other supplementary policies, such as penalty policies and subsidy policies. Ortas and Álvarez [31] focused on the efficacy of the EU-ETS, and proposed a non-modelling way to estimate the relationship between carbon assets and energy commodities (both high and low frequencies). Fan et al. [32] examined the price, substitution and income impact of variations of ETS prices by proposing a general utility model which is optimized by constant elasticity of substitution utility function.

Many methods are used to study energy policy, such as econometric methods [33], input-output analysis [34], LMDI (Logarithmic Mean Divisia Index) [35], partial equilibrium model [36], and CGE model [37], such as Dai et al. [38] assessed the impacts of large-scale development of renewable energy in China toward 2050 using a dynamic CGE model. This paper utilizes a CGE model to study the issue of allowance allocation mechanism on electricity industry, because CGE model can analyze the environment, economy and energy impact of energy policy. It also can explain many aspects of market behavior and is a model that is very conducive to analysis [39].

There are several researches analyzing ETS based on CGE model. Dai et al. [40] and Qi and Weng [41] evaluated that if China achieves *China's Intended Nationally Determined Contributions* by applying ETS, what kind of impact will the economy be subjected to? Yu et al. [42] analyzed the impacts of regional and sectoral emission quota allocation on carbon trading market. Wu et al. [43] evaluated the impact of ETS policy on economy in Shanghai, which is one of eight ETS pilot provinces and cities in China, by applying a static computable general equilibrium (CGE) model. Wang et al. [44] analyzed the impact of carbon ETS policy among four energy intensive sectors in Guangdong province. Wu et al. [45] analyzed the impact of ETS policy when combined with renewable energy source policies in China. Fujimori et al. [46] showed the benefit of emissions trading under both nationally determined contributions and a more ambitious reduction scenario consistent with the 2 °C goal. Cheng et al. [47] assessed the impacts of carbon ETS on air pollutant emission reduction in Guangdong Province. Liu et al. [6] simulated the economic and environmental impacts of the Hubei Pilot ETS. Pradhan et al. [48] estimated ETS prices in China and India and then compared the effects of carbon pricing policies in the context of international trading. Brink et al. [49] studied various potential choices to adjust ETS prices in the EU-ETS, such as changing the carbon cap, adjusting an auction reserve price, and adding fixed and variable carbon taxes to complement EU ETS. Liu et al. [50] used CGE model to analyze the economic and environmental impacts of ETS in Hubei, which is an ETS pilot province.

Annual Decline Factor (ADF) and calculation method are the key allowance allocation mechanism, however, less researcher focused on the two key variables of the mechanism, which will be introduced and described in Section 2.2.1 and Section 3. Moreover, electricity industry contributes nearly half of CO_2 emissions among all industries in China. Thus, this paper will explore the impact of different allowance allocation mechanism of ETS on electricity industry in order to seek the solution for improving its mechanism on electricity industry.

Most of literature focuses on the impact of aggregate ETS, and the scope of research is relatively macroscopic. Nevertheless, the detailed analysis of the impact of allowance allocation mechanism of ETS on a single major industry is ignored, such as electricity or other energy-intensity industries. The research on this issue can render better understanding of the mechanism of ETS and can push the policies related to carbon trading mechanisms more detailed and in-depth all over the world, as almost all of ETS market have covered electricity industry, such as EU-ETS, RGGI etc., see Table 1. This paper tries to answer the question of how to design the carbon trading mechanism for electricity

Table 1
The main abbreviations in this paper.

Abbreviation	Region	ETS market	Covering industry
EU-ETS	Europe	The EU Emissions Trading System	Phase I: electricity, oil, steel, cement, glass, paper etc. Phase II: adding air traffic. Phase III: almost every industry
ETG	U.K.	UK Emissions Trading Group	Voluntary
RGGI	U.S.	Regional Greenhouse Gas Initiative	Electricity
MGGRA	U.S.	Midwest Greenhouse Gas Reduction Accord	Electricity, steel, cement, commercial
CCX	U.S.	Chicago Climate Exchange	Voluntary
NSW-GGAS	Australia	New South Wales Greenhouse Gas Abatement Scheme	Electricity