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The impacts of emissions accounting methods on an imperfect competitive carbon trading market

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ABSTRACT

To achieve a reduction in carbon intensity, the Chinese government has committed to establishing a nationwide carbon market. In this study, an interregional input-output model is proposed to derive cost curves for regional marginal abatement and to estimate interregional embodied emissions. An emissions trading model is presented for exploring the impacts of emissions accounting methods on imperfect competitive trading markets in the context of China achieving its 12th FYP intensity reduction target. The results indicated that emissions permits could be reallocated according to the CBA method. This could reduce both carbon emissions and total cost. Compared to the PBA method, the CBA method could lead to a greater change in permit prices and the amount of carbon trading in an imperfect competitive carbon market. Moreover, more regions with market power could cause declines in permit prices, resulting in changes in abatement costs. In addition, seven pilot markets (excluding Hubei province) are net embodied emissions importers. Pilot trading schemes in China could lead to carbon leakage among the other non-trading regions and sectors.

1. Introduction

In 2015, the Chinese government proposed an Intended Nationally Determined Contributions (INDC) to the Secretariat of the UN Framework Convention on Climate Change. The INDC included the intention to achieve peak carbon dioxide emissions by around 2030 and to lower the carbon dioxide emissions per unit of GDP by 60–65% from the 2005 level. To achieve the goal, China cannot continue to rely only on costly administrative measures; it must also increasingly turn to market-based methods. An emissions trading system (ETS) was introduced in seven pilot programs at the province and city level in 2013, and China is to implement a nationwide carbon market in 2017.

Because carbon markets have been advocated as the most promising, efficient, and effective policy instrument to avoid serious climate change, scholars from various countries have been studying the methods and likely results of carbon trading. Cui et al. pointed out that carbon emissions trading leads to different impacts among the provinces and the cost-saving effects for China's eastern and western regions are more significant than are those for the central regions [1]. Similarly, Zhou et al. proposed that China's total emissions abatement cost could be reduced by 40% by implementing such a trading scheme [2]. Wang et al. estimated the potential gains from carbon emissions trading and found that all of China's 30 provinces could have abatement cost savings or GDP loss recoveries through carbon emissions trading [3]. Wu et al. analyzed the regional macroeconomic impacts of emissions trading in China under different quota allocation criteria and allocation methods using a multiregional computable general equilibrium (CGE) model [4].

In addition to those studies of the economic impacts of emissions trading, some researchers have provided overviews of permit pricing in carbon trading [5,6], and others have investigated market coalitions in the carbon market. Jotzo and Löschel, Zhang et al., and Liu et al. pointed out that large differences exist in the design of these pilots and that these differences reflect the diverse settings and properties of the emissions trading schemes [7–9]. Liu et al. examined the carbon abatement effects of several intra-provincial emissions trading markets and a linked inter-provincial market [10]. Liu and Wei, and Hübler et al. measured the benefit to China of

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linking its ETS to the EU ETS [11,12].

Within the interregional carbon market, provinces with higher net trading volume would typically have larger volumes of embodied emissions and a stronger influence on carbon pricing. Emissions embodied in trade are therefore important for defining the regional carbon dioxide emissions reduction and its exogenous ceiling. Many studies compared the different responsibilities with an input-output model to assess energy and carbon emissions embodied in interregional trade, and which accounting methods for emissions trading lead to more effective environmental regulations and policies [13–15]. Cortés-Borda et al. found that a consumption-based method facilitates the design of environmental regulations and policies that are more effective [16]. Some studies examined the challenges and opportunities of introducing an emissions trading system to the energy and energy-intensive sectors (i.e., power, refinery, cement, iron and steel, transportation, construction, and supermarket sectors) [17–24].

Moreover, emissions accounting methods in imperfect competitive markets will have important effects that could prevent market failures and improve the efficiency of resource allocation. Hahn noted that a firm would have market power if it realizes that it has an influence on price. His result indicated that to minimize total abatement costs, policymakers should avoid situations in which the firm with market power acts as a monopolist [25]. Dijkstra et al. considered that if an expansion results in a steeper marginal abatement cost curve for a country's remaining non-trading sectors, the country would lose its ability to manipulate the international permit price in its favor, and thus might see its overall costs increase [26,27]. These theoretical and empirical analyses of emissions trading do not, however, take emissions accounting methods and their economic impacts on carbon emissions markets into account [28].

This paper develops a multi-regional input output (MRIO) model for China to analyze the effects of a nationwide carbon market on regional economies, and the impacts of various emissions responsibilities on carbon trading equilibrium at regional and industrial level. The aim of this paper is to present a MRIO analysis of China's interregional embodied carbon emissions transfers via domestic trade in 2007 by using the MRIO table. The MRIO modeling can not only reveal the interregional embodied carbon emissions transfers, but also estimate the all regional and industrial marginal abatement cost curves (MACs). Such analyses can identify regional carbon emissions features and reflect the emission responsibilities of different regions in consideration of regional diversity and complexity. Based on embodied emissions and MACs research, the present paper establishes an emissions trading model that captures decision-making optimization among trading sectors. The combination of emissions trading and MRIO models achieves the effective simulation and extensive analysis of the impacts of unified carbon trading markets on regional cost-effectiveness of emissions abatement.

2. Methodology

To assess the impacts of various emissions responsibilities on carbon trading equilibrium at regional and industrial level, the carbon trading in a MRIO model is proposed. MRIO model is a China-based multi-regional energy-environment-economy input output model that include 30 regions and 21 production sectors (see Appendix Table A.2).

2.1. Theoretical description for regional emissions responsibility and carbon markets

The logarithmic marginal abatement cost function is described in Equation (1) (see Appendix A):

$$MC_{r,h}(s_{r,h}) = a_{r,h} + b_{r,h} \cdot \ln(1 - s_{r,h}) \tag{1}$$

where n and m is the number of regions and sectors, $r = 1, \ldots, n.;\ h = 1, \ldots, m.;\ h \in (T, NT)$, respectively. Region r has an exogenously given emissions ceiling of E_r. The CO_2 emissions in each region are divided into trading sectors, T, and non-trading sectors, NT. Assuming the initial emissions levels is $e^0_{r,T}$ and $e^0_{r,NT}$, the total reduction cost is $TC_{r,T}$ in region r's trading sectors and $TC_{r,NT}$ in the non-trading sector, and marginal abatement costs of $MC_{r,T}$ and $MC_{r,NT}$. s is a reduction ratio of total emissions, the values for a and b are the coefficients in the marginal abatement cost function of the various sectors in region r. Equation (1) can be rewritten as a function of the carbon-trading emissions $e_{r,T}$ as follows:

$$MC_{r,T}(e_{r,T}) = a_{r,T} + b_{r,T} \cdot \ln\left(1 - \frac{e^0_{r,T} - e_{r,T}}{e_{r,T}}\right) \tag{2}$$

Assuming the emissions reduction $A_{r,T} = e^0_{r,T} - e_{r,T}$, the costs of abatement in region r are described in Equation (3).

$$\begin{aligned} TC_{r,T}(e_{r,T}) &= \int_0^{A_{r,T}} \left[a_{r,T} + b_{r,T} \cdot \ln\left(1 - \frac{x}{e_{r,T}}\right)\right] dx \\ &= -b_{r,T}(e_{r,T} - A_{r,T}) \ln\left(1 - \frac{A_{r,T}}{e_{r,T}}\right) - b_{r,T}A_{r,T} + a_{r,T}A_{r,T} \end{aligned} \tag{3}$$

The overall abatement costs in the market are described as the costs of abatement plus net expenditures for buying (or selling) permits from (or to) the other regions.

$$TTC_{r,T}(e_{r,T}) = TC_{r,T}(e_{r,T}) + P(e_{r,T} - d_r) \tag{4}$$

Assuming the allocated emissions budget d_r for the trading sector plus the emissions $e_{r,NT}$ for the non-trading sector must add up to the permit allocation. The emissions $e_{r,T}$ for the trading sectors minus allocated emissions budget d_r for the trading sectors must equal the net buying (selling) permits from (to) external regions.

Each region r minimizes total costs of abatement as follows:

$$\begin{aligned} &\text{Min } TTC_{r,T}(e_{r,T}) \\ &\text{s.t.} \sum_r A_{r,T} = \sum_r \left(e^0_{r,T} - d_r\right) \text{ or } \sum_r e_{r,T} = \sum_r d_r = e_T \end{aligned} \tag{5}$$

The real emissions reduction $A_{r,T}$ is given by the well-known first-order condition:

$$A_{r,T} = e_{r,T}\left(1 - \exp\frac{(P - a_{r,T})}{b_{r,T}}\right) \tag{6}$$

Thus, the equilibrium permit pricesP^* and emissions reduction $A^*_{r,T}$ are described as follows:

$$\sum_r A_{r,T} = \sum_r e_{r,T}\left(1 - \exp\frac{(P - a_{r,T})}{b_{r,T}}\right) = \sum_r \left(e^0_{r,T} - d_r\right) \tag{7}$$

Equation (7) implicitly defines$e_{r,T}$, $a_{r,T}$ and $b_{r,T}$ as functions of the equilibrium results (P^* and $A^*_{r,T}$) in the market.

In a perfect competitive market, we assumed that each trading individual is too small to have market power, and so each region takes the permit price P as given, Equation (6) is then described as follows: