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TOWARDS A SYSTEMATIC FRAMEWORK FOR THE MODELLING OF THE ALLOCATION OF CARBON DIOXIDE EMISSION QUOTAS IN CHINA

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Abstract: The needs for effectively controlling carbon dioxide emissions and properly allocating carbon dioxide emission permits or allowances in China have never been so great. In this paper, a systematic multi-agent-based framework for the modelling and analysis of the allocation of carbon dioxide emission quotas in China is proposed. A carbon trading market model as the core of the activities of allocation management is constructed and discussed. In addition, examples of the modelling and simulation work are presented.

Keywords: Emission control for Carbon Dioxide, Allocation of Carbon Dioxide Emission Quotas, Chinese Carbon Market, Modelling, Computer Simulation.

1. INTRODUCTION

The world is faced with the huge threats of global warming. Low carbon economies are the important mode of development for dealing with the climate change. The Chinese government aims to build up a national carbon emission trading market gradually through pilot work and experiments, and wants to use the market mechanism to regulate the emissions of greenhouse gases, including carbon dioxide.

Nevertheless, because the experimental cities and pilot provinces in China adopt a top-down approach towards carbon emission data collection and emission target setting, carbon quota surplus has existed. On the other hand, Chinese enterprises have not fully recognised and realised the value of carbon emission permits or allowances as assets. When the prices of emission quotas go down, enterprises may lack motivation for carbon emission reduction. Therefore, effective frameworks, models and tools are urgently needed to support the analysis, forecasting and evaluation of carbon quota management activities.

2. RELEVANT WORK IN THE LITERATURE

Gagelmann [1] investigated the history-based allocation mechanism for carbon quotas. Fowlie and Perloff [2] supported the use of the auction method. Linghu and Ye [3] explored carbon emission allocation policies for various carbon quotas under duopoly competition.

Ma et al. [4] analysed the inter-relationships amongst enterprise product pricing, emission reduction marginal costs and target emission decision-making. Ma et al. [4] also conducted research on how to determine optimal carbon emission, optimal price and profit maximisation.

Carmona [5], and Frunza et al. [6] explored respectively the factors that affect the prices of carbon quotas.

3. A FRAMEWORK FOR THE MODELLING ANALYSIS OF CARBON QUOTA ALLOCATION

Multi-agent-based modelling and computer simulation paradigms are applied to represent and analyse the Chinese carbon market problem. The carbon market model consists of three agents: government agent, enterprise agent, and carbon trading market agent.

The government agent is created to describe the government's responsibilities for allocating carbon emission quotas. The enterprise agent is designed to model enterprise trading activities in the market, on the basis of emission reduction costs and carbon prices. The market agent is designed to deal with trading rules and pricing for carbon emission quotas.

3.1. Government agent

The main aim of the government agent is to reduce the emissions of carbon dioxide. Its management activities include: allocating carbon quotas, devising and regulating emission targets, auction, buying quotas back, etc.

According to different goals or targets of emission reduction, the government makes and sets associated emission reduction coefficients ranging from loose to strict levels of control, and manage the granted amount of quotas. These activities have

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impacts on the changing costs of emission reduction, and also have influence on enterprise behaviour.

Taking into account carbon prices and the trends of supply-demand relationships in the market, the government adjusts and modifies the value of the emission reduction coefficients, and repurchase or auction carbon quotas, for the purpose of enabling the stable and healthy evolution and development of the carbon market.

The degree of government satisfaction is measured using a combination of quota delivery ratio and compliance enterprise ratio. This is an extension of Wang [7]'s water rights trading model. It is expressed as follows.

$$S(t) = \omega_0 \frac{\sum E_{ij}(t)}{\sum A_{ij}(t)} + \omega_1 \frac{CEA(t)}{CE(t)} \qquad (1)$$

where S(t) stands for the level of government satisfaction; $A_{ij}(t)$ denotes the allocated quota for enterprise *i* of industrial sector *j* at time period *t*; $E_{ij}(t)$ represents the emission volume of enterprise *i* of industrial sector *j* at time period *t*; *CEA*(*t*) denotes the number of compliance enterprises; *CE*(*t*) strands for the total number of enterprises; ω_0 and ω_1 are the symbols for weights.

Computer simulation has been conducted. As shown in Fig.1, the yellow line and the black line respectively indicate the degree of government satisfaction on the carbon trading market under tightly and loosely controlled situations. We can see that the yellow line is just below the black one. This indicates that the level of government satisfaction is lower when the circumstance is harsh, for the reason that strict conditions make emission reduction more difficult, and thus lead to smaller ratio of reduction.

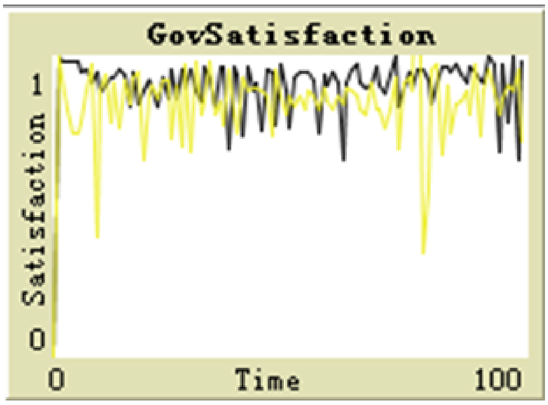

Fig.1. The Simulation output of government satisfaction

3.2. Enterprise agent

Different types of enterprises in the carbon market may have different goals. Low carbon enterprises may aim to maximize their profits of emission reduction, while high carbon enterprises may hope to minimize the costs of emission reduction.

At the beginning of each time period, enterprises should first decide to sell or buy, and calculate the optimal volume of emission reduction for themselves, on the basis of acquired quotas, estimated carbon prices and marginal cost curve of emission reduction.

A general decision making process can be stated below. Information gathering, acquiring quotas for carbon dioxide emissions, forecasting prices for quotas, analysing marginal cost curve for emission reduction, deciding to buy or sell, and working out optimal emission reduction amount.

The forecasting price for a carbon dioxide quota is formulated as:

$$PEC_{ij}(t) = PC(t-1) \times e^{\left(\theta \times \frac{AD(t-1)-AS(t-1)}{|AD(t-1)-AS(t-1)|}\right)} \times (1+\varepsilon_t) \qquad (2)$$

where $PEC_{ij}(t)$ denotes the carbon quota price predicted by enterprise *i* of industrial sector *j* at time period *t*; $PC(t-1)$ is the carbon quota price at time period (*t-1*); θ is a positive random number; $AD(t-1)$ stands for the quota demand amount in the market at time period (*t-1*); $AS(t-1)$ stands for the quota supply amount in the market at time period (*t-1*). In this formula, ε_t is cited from Wei [8]'s work. It is a random disturbing item and represents other factors influencing carbon prices. $\varepsilon_t \sim N(0, 0.01^2)$.

Fig.2. Illustrates carbon price simulation.

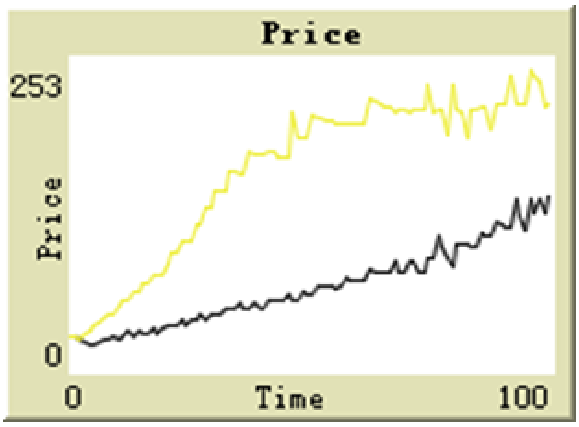

Fig.2. The sample output of carbon price simulation

In Fig.2, the yellow line and the black line respectively represent the carbon prices under tightly controlled and loosely regulated situations. The general trends of carbon prices are going up, with some local fluctuation.

Fig.3. Shows the simulation output for the volume of emission reduction.

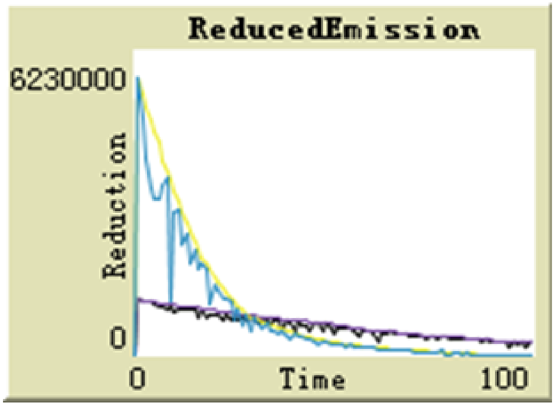

Fig.3. Simulation of the volume of emission reduction

In Fig.3, the yellow line represents the required or expected volume for emission reduction under harsh conditions. The blue line stands for the completed volume of reduction under strict circumstances. The black line indicates the required volume of emission reduction under loose situations. The purple line denotes the completed volume of reduction under slack regulations. Generally speaking, the yellow line is close to the blue one. And the black line is very close to the purple one. This indicates that emission reduction goals can be achieved through the enterprises' activities in the carbon dioxide trade market.

Fig.4. Illustrates the simulation output for the net benefit of unit volume of emission reduction. This is a dynamic proportion result of the total net benefit of all the enterprises divided by the total volume of emission reduction of all the enterprises.

In Fig.4, the yellow line represents the enterprise unit net benefit of emission reduction under a situation with harsh control, while the black line denotes unit net benefit under a slack regulation. During the first quarter phase of the simulation run, the yellow line is above the black. This suggests that the potential for emission reduction is relatively greater during early stage, and enterprises can get larger unit net benefits through carbon quota trading. During the later three quarters of the time period, the yellow line is below the black. This implies that the level of difficulties for emission reduction increases in later stage. It would be more difficult for enterprises to obtain higher unit net benefit. Generally speaking, it is easier for enterprises to achieve bigger unit net benefits under loosely controlled situations.

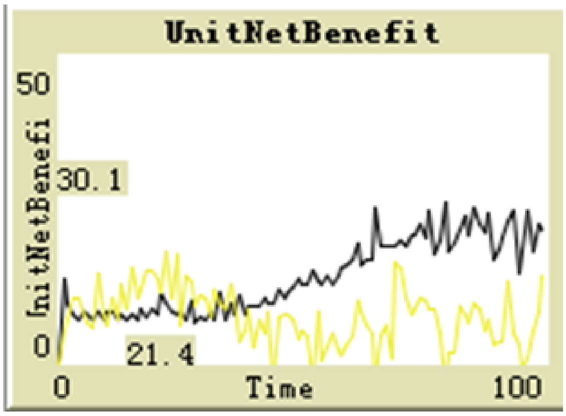

Fig.4. The simulation result for the net benefit of unit volume of emission reduction

3.3. Carbon trading market agent

Here, the market agent represents the activity of carbon emission rights exchange, and formulates rules for carbon trading.

Obviously, with different trading rules, the carbon price formation mechanisms are also different. The method used in this study is a method of bidding and matching of selling and buying parties. Successfully matched enterprises make exchange under certain prices. Unmatched enterprises also trade on the condition that the computed net benefit is positive under specified prices.

For the purpose of simplicity, only cross period storage for quotas is allowed. The costs for monitoring, reporting and verification are not considered.

Fig.5 shows the simulation result for trade.

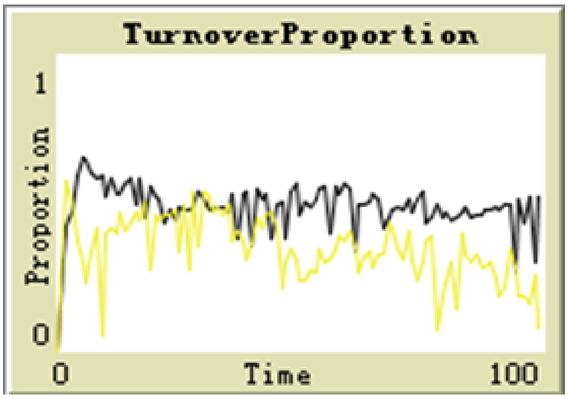

Fig.5. Simulation of trade in the carbon market

As shown in Fig.5, the yellow line and the black line respectively denote the turnover proportion of trade volume to emission reduction volume, under tightly controlled and loosely regulated circumstances. It is clear that the black line is above the yellow one. This implies that, under relaxed situations, the ratio of exchange volume to emission reduction volume is relatively bigger.

CONCLUSIONS

This study has been sought to establish a systematic framework for the modelling of carbon dioxide emission quota allocation in China. The roles and activities of the government, enterprises and the carbon trade market are analysed, described and demonstrated. Examples of computer simulation outputs are also presented and discussed.

On the basis of the proposed framework, simulation runs have been conducted. It have been shown that, under loose control, the government is more satisfied with the carbon trade market. And the unit net benefit for enterprises is higher with an upward trend.

On the other hand, with tight and harsh control, enterprises are under lots of pressure. The phased target for emission reduction can be quickly achieved. However, in later stage of a period of time, enterprises may lack enthusiasm. And the market makes less contributions to carbon dioxide emission reduction.

It is recommended that, when the control is harsh with high coefficients for emission reduction, and when enterprises are under big pressure, the government should provide bonus and allowances to support and encourage the low carbon activities of enterprises.

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