A Multi-Agent Model to Analyze CO_2 Emissions Trading

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Abstract

The purpose of this paper is to describe a multi-agent simulation model developed in order to analyze CO_2 emissions trading. Unlike general traditional economic methods, multi-agent models are a bottom-up approach and make analysis of complex social and economic systems such as emissions trading possible without strong economic assumptions which are far from reality. That is to say, it is possible to simulate such systems under conditions closer to the real world, for example bounded rationality, by applying multi-agent models. In the developed model, micro-agents are heterogeneous and bounded rational. Then, simulation is implemented only through interactions among the micro-agents and among the micro-agents and macro-systems.

Keywords: Multi-Agent Model, CO_2 Emissions Trading, Bounded Rationality, Economic Analysis

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1. Introduction

Concerning the Kyoto Protocol, CO_2 (and GHG) emissions trading attracts the attention. Accordingly, a number of studies and analyses related to the topic are implemented recently. However, most of such studies have used economic models and introduced traditional strong economic assumptions such as the representative individual and the perfect rationality to avoid difficulties in analysis. As a result, equilibrium solutions are introduced under such assumptions by a top-down approach using sophisticated mathematical formulae, in which some important and complex conditions of economic systems are omitted. However, the real world which is based on interactions among economic entities, and among economic entities and systems is extremely complex. Also, the behavior of economic entities is bounded rational. In addition, it is not always in the equilibrium state. Therefore, while traditional economic methodologies are easy to operate and useful to observe rough results of such complicated behavior, they are not enough to analyze social and economic problems in detail. In addition, there is possibility that misdirected outcomes are drawn.

In this paper, effectiveness of a multi-agent model for emissions trading analysis is described through explanation of its characteristics.

2. Traditional Economic Analysis of Emissions Trading

As described above, a number of studies about emissions trading have been implemented using economic models. Especially, applied general equilibrium analysis is used frequently. AIM/Top-down model (Kainuma et al. (1999)), GTAP-E (Burniaux and Truong (2002)), MERGE (Manne and Richels (1998)), GREEN (Burniaux (1999)), RICE (Nordhaus and Yang (1996), Nordhaus (2001)), WorldScan (Bollen et al. (2000)), Babiker (2001), and Saijo (2006) can be given as the examples using applied general equilibrium analysis. Some of the models are static and the others are dynamic.

Springer (2003) summarizes some model studies analyzing emissions trading. It shows not only applied general equilibrium models and other economic models but also other kinds of models such as energy system models. However, most of the models surveyed are based on applied general equilibrium analysis.

Considering the characteristics of emissions rights, they are very different from general goods and similar to stocks and other financial products. In fact, trade price of emissions rights fluctuates continuously and widely[1] unlike price of general goods. Nevertheless, one price or one price in a year of emissions rights is determined in the case of traditional economic methods. Moreover, although they assume that the behavior of economic entities is perfectly rational, it is not realistic. The actual behavior of economic entities is bounded rational. Consequently, although traditional economic methods are very useful to understand the tendency of the outcome of emissions trading as described above, they are not the optimum method.

3. Multi-Agent Model

Unlike traditional economic models, multi-agent models are a bottom-up approach. It starts from activities of micro-agents and macro-systems or macro-phenomena are emerged as a result of complicated interactions among micro-agents. Micro-agents are independent, autonomous, and heterogeneous existences and the constituent is various. The model focuses on the behavior of micro-agents and tries to understand the emergent macro-phenomena (Mizuta and Yamagata (2001a)). Therefore, any systems to control the whole model do not exist. In the model, because the autonomous micro-agents act independently and dynamically depending on the local information and the criteria of their own, that is bounded rationality is assumed, this approach is able to express the condition of social systems in which dynamic interactions among micro-agents and among micro-agents and macro-systems are observed properly. In this manner, it is possible to analyze under the more realistic assumptions by applying multi-agent models.

Multi-agent models can be used for various types of studies from natural science to social science. For example, ecosystem, traffic jam, political negotiation, stock market, and communication have been studied with this approach (Arthur et al. (1996), Kaneda (2005), Yamakage and Hattori (2002)). Recently, market analysis based on this approach is getting attention (Izumi (2003), Mizuta and Steiglitz (2000), Mizuta et al. (1999), Shiozawa et al. (2006), Steiglitz et al. (1996)). In addition, it is also applied to analyze emissions trading (Kimura and Oda (2002), Mizuta and Yamagata (2001a, b), Oda et al. (2003)). However, the framework of this methodology has not been consolidated, yet, in spite of its availableness.

4. Analysis of Emissions Trading Using Multi-Agent Model

When developing a multi-agent model to analyze emissions trading,

[1] See European Climate Exchange (2007).

thought of a bottom-up approach with bounded rationality of agents is essential.

Although multi-agent models have been used to analyze emissions trading in some studies such as Kimura and Oda (2002), Mizuta and Yamagata (2001a, b), and Oda et al. (2003) such studies are still rare so far. The multi-agent model developed in this study (the developed model) is based on Kimura and Oda (2002) and Oda et al. (2003) (the base model). However, the developed model has some different points from the base model. The main differences are the following: 1) although the base model considers marginal abatement cost (MAC) constant for each country (agent), MAC functions are prepared to calculate MAC in the developed model, 2) although the base model can treat only countries whose emissions rights are less than the emissions, the developed model can treat countries whose emissions rights are less than, equal to, and more than the emissions.

In the developed model, two trade methods, double auction and bilateral trade, are considered following the base model. Countries (Agents) act aiming to abate CO_2 emissions below the emissions rights and to minimize the abatement cost (or to maximize the profit). Unlike traditional economic analysis, countries behave based on the own local information. The information each country depends is the MAC function, the CO_2 emissions, the emissions rights, and the strategies.

Behavior of countries is classified into the following three stages. The first stage and the third stage are identical, but the second stage is different depending on the trade method. Also, Fig.1 and Fig.2 show the structures of trade in the model.

1. Establishment of an annual plan
2. Trade
3. Self-abatement

The first stage is a process to determine a CO_2 amount each country expects to abate and trade in the year. There are three types of choices according to the CO_2 emissions and the emissions rights of each country (Fig.1-II and Fig.2-I). If a country has the emissions rights less than the CO_2 emissions (Type A), it can be either a buyer or a seller of emissions rights. It determines the expected amount to abate by itself and through IET in the year based on its self-abatement rate, its deficient emissions rights, and remaining years. It also determines the expected amount of the emissions rights it is willing to sell and buy where the amount to buy is thought to be larger than that to sell. If a country has the emissions rights equal to the CO_2 emissions (Type B), it can be a seller and determines the expected amount it is willing to sell based on the emissions rights. Then, if a country has the excess emissions rights (Type C), it can be a seller and determines the expected amount it is willing to sell based on the excess amount and remaining years.

This process is implemented once at the start of a year.

Concerning double auction, the process of the second stage is as follows. Considering Type A, each country selects a strategy (Fig.1-III), determines a bid amount (Fig.1-II), and calculates MAC (Fig.1-IV) to determine a bid price. Each strategy is composed of a position, which determines to be a buyer or a seller, and a range of bid price, which determines how much to add on (reduce from) the MAC to bid to sell (buy). In addition, an evaluation value, which indicates how the strategy is superior, is assigned to each and it is selected randomly with the probability proportionally to the evaluation. The larger the value, the superior the strategy is. The bid amount is determined according to the expected buying or selling amount obtained in the first stage. Bid price to sell (buy) is determined to be able to gain profit (reduce cost) from trades and self-abatement certainly. Therefore, bid price to sell (buy) is calculated by adding (reducing) the range of bid price obtained from the selected strategy on (from) the MAC. Then, the above information is sent to the exchange (Fig.1-I).

Considering Type B and C, because each country only can be a seller, information about the bid amount is determined based on the expected selling amount obtained in the first stage and is sent to the exchange (Fig.1-I). Then, it is considered that its bid price is set equal to the cheapest bid price to sell in the exchange.

When bids are gathered in the exchange, trade is started ("Trade" in Fig.1-I). It is implemented from a buyer with the highest bid price to buy and a seller with the lowest bid price to sell as long as both sellers and buyers exist and the highest bid price to buy is not lower than the lowest bid price to sell. Each trade price is settled as the average of the bid price to sell and the bid price to buy. If there is more than one selling or buying bid with an identical bid price, the earlier one has priority to trade. Also, bids by Type B and C are prior to those by Type A to trade.

Next, concerning bilateral trade, the process of the second stage is as follows. Concerning Type A, each country selects a strategy to offer (Fig.2-II), determines an offer amount (Fig.2-I), which is an expected trade amount, and calculates MAC (Fig.2-IV) to determine an offer price. Each strategy is composed of a position, which determines to be a buyer or a seller, a range of offer price, which determines how much to add on (reduce from) the MAC when offering to sell (buy), and a target, which is to determine a trading partner. In the same manner as double auction, an evaluation value is assigned to it and it is selected randomly with the possibility proportional to the evaluation. The offer amount is determined according to the expected buying or selling amount obtained in the first stage. The offer price to sell (to buy) is determined to be able to gain profit (to reduce cost) from trade and self-abatement. Therefore, the offer price to sell (to buy) is calculated by adding (reducing) the range of offer price obtained from the selected strategy on (from) the MAC. Then, the information about the offer price and offer amount is sent to the trading partner determined by the selected strategy. When a country of Type A receives a offer message, it determines whether to accept or reject it by selecting a strategy to answer (Fig.2-III). Each strategy is composed of a target to receive an offer message and a range of price to add on (reduce from) MAC when receiving offers to buy (sell) like strategies to offer. If the offer price to buy (sell) from the determined trading partner is higher (lower) than the MAC plus (minus) the range of price of the receiver, the offer message is accepted and the entire offer amount is traded. The offer price is treated as the trade price. On the contrary, the offer message is rejected if the offer price to buy (to sell) is lower (higher) than the MAC plus (minus) the range of price of the receiver.

Concerning Type B and C, they do not send any offer messages and only receive the messages. Because each country only can be a seller, it does not use strategies to determine the behavior and it accepts offers to buy and rejects those to sell. The offer price is treated as the trade price and the entire offer amount is traded.

Each time a trade is made, the evaluation values on all of the selected strategies are updated (both double auction and bilateral trade). Since success of trade means success of the selected strategy, the evaluation on it is raised. On the contrary, since failure of trade means failure of the selected strategy, the evaluation on it is lowered. The evaluation is changed proportionally to the range of price. This is reinforcement learning. Because countries of Type B and C do not use strategies, this process is implemented only for countries of Type A.

Either process of this stage is repeated some times a year.

The third stage is a process to abate CO_2 emissions by itself ("SA" in Fig.1-II and Fig.2-I). This model assumes that each country abates its CO_2 emissions over its emissions rights by itself as a result of emissions trading and it is implemented every year. Although the self-abatement amount is determined according to the self-abatement rate, it is assumed that the CO_2 emissions become equal to the emissions rights in each country in the end by self-abatement in this model[2].

This process is implemented once in the year-end.

The developed model is constructed using a simulator, KK-MAS, developed by KOZO KEIKAKU ENGINEERING Inc..

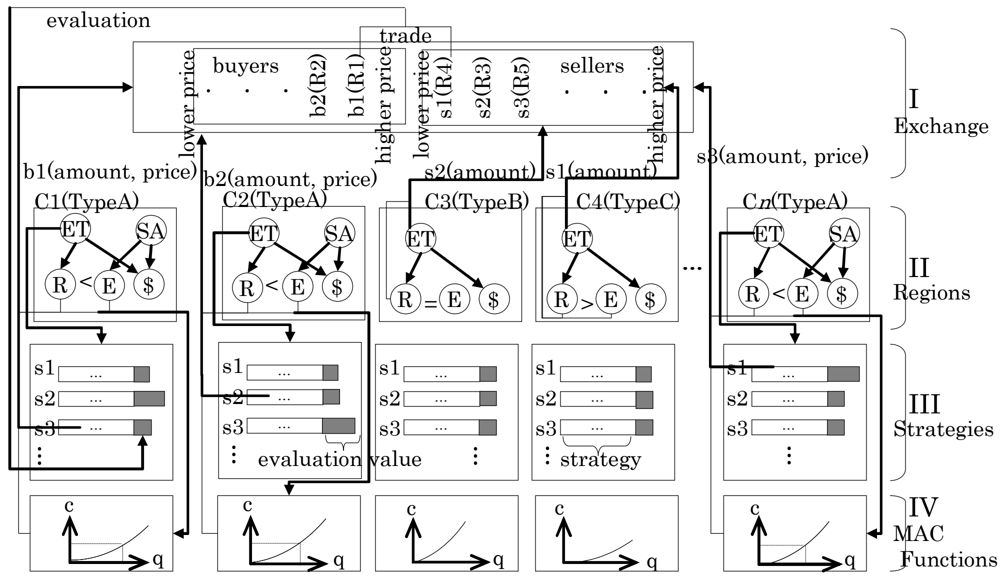

Fig.1 Double Auction

* C: country, ET: emissions trading, SA: self-abatement, R: emissions rights, E: CO_2 emissions, $: money, s: strategy, c: MAC, q: abatement level

[2] However, there is possibility that emissions rights are larger than CO_2 emissions.

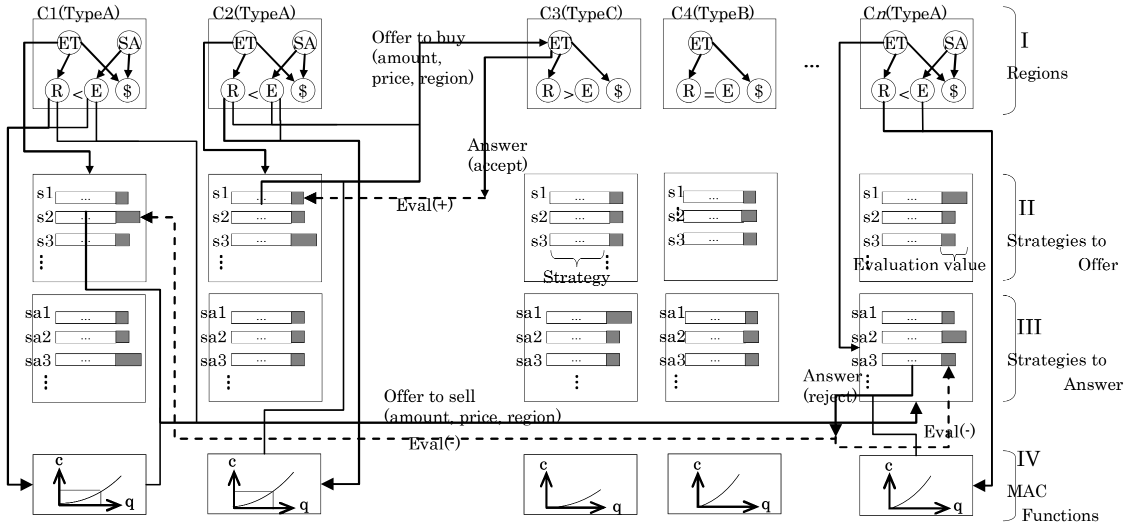

Fig.2 Bilateral Trade

*C: country, ET: emissions trading, SA: self-abatement, R: emissions rights, E: CO_2 emissions, $: money, s: strategy to offer, sa: strategy to answer, Eval(+): positive evaluation, Eval(-): negative evaluation, c: MAC, q: abatement level

5. Concluding Remarks

In this paper, a multi-agent model for CO_2 emissions trading analysis is introduced. Unlike traditional economic analysis, this bottom-up approach focuses more on the dynamic activities of autonomous micro-agents and the complicated interactions. In addition, they are independent, heterogeneous, and bounded rational. Therefore, analysis is implemented under the more realistic assumptions.

The framework of the developed model is simple and only emissions trading market can be analyzed like partial equilibrium analysis. However, it is important to link the emissions market with other markets and economic entities to take into account the influences of interactions among them like general equilibrium analysis. Therefore, investigation of methods to incorporate the behavior of other markets and economic entities into the model is necessary. Furthermore, devising good ways and means about the behavior of micro-agents and trade methods should be considered to make the model more similar to the real situations.

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