International Emissions Trading as a Climate Change Policy Considering a Fine: An Analysis Applying a Multi-Agent Model

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Abstract

Greenhouse gas (GHG) emissions trading is one of the most important methods to contribute to cost-efficient GHG emissions abatement. When introducing the scheme, it is necessary to determine various institutional frameworks and it is significant to estimate the effects and influence in advance. In this study, the effects and influence of a fine system, which is regarded as one of the most considerable frameworks, are investigated. In the analysis, a multi-agent model is applied. Namely, agents' decision making is based on the local information and emissions trading process is sufficiently considered unlike traditional economic models.

From this study, the influence of the fine level on emissions trading and environment are revealed. In addition, the effects and influence on the countries participating in emissions trading and their decision making are clarified. Then, it is also shown that a certain fine level is appropriate to make the framework acceptable and certainly complete the emissions abatement target simultaneously.

Key Words: Multi-Agent Model, International Emissions Trading, Fine, Kyoto Protocol, Emissions Abatement

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1 Introduction

Greenhouse gas (GHG) emissions trading is attracting attention as a climate change policy to abate GHG emissions cost-efficiently. Especially, since the climate change policies and measures have not been progressed satisfactorily so far even though the first commitment period of the Kyoto Protocol has come, it is expected to play an important role in the international level under the Kyoto Protocol to accomplish the target. In the present situation, however, emissions trading in the global level does not exist, and only that in the regional level (e.g. EU Emissions Trading Scheme (EUETS)) and the internal level (e.g. UK Emissions Trading Scheme and Chicago Climate Exchange) exists. Therefore, there is enough room for discussions about the framework. Considering the existing emissions trading systems and the other conceivable systems, possible frameworks of emissions trading are diverse. For instance, a sort of GHG to trade, a scope of participants, allocation methods of emissions rights, trade methods, penalties, and so on must be considered. Among them, participants' decision making will be affected significantly whether some penalties are imposed or not. Unless some kind of penalties is introduced, compliance to achieve the emissions abatement target is not assured. In other words, penalties will undertake a crucial role to meet the commitment.

In this article, the effects and influence of a penalty on the emissions trading system, participants, and emissions abatement are analyzed quantitatively applying a multi-agent simulation model. Although various kinds of penalties such as carry-over of the noncompliance emissions amount to the next commitment period and prohibition to participate in emissions trading when the abatement target is not attained can be considered for emissions trading, a financial penalty, a fine, is taken up in this study because it is one of the simplest methods. In order to confirm compliance of the emissions abatement target, introduction of a fine system will be important. As to introduce an international emissions trading system in reality, it has significant meaning to clarify the relation between the emissions trading and fine, and to construct an effective framework of emissions trading as a result. So far, traditional economic methods, which are top-down approaches, such as applied general equilibrium models have been used to analyze emissions trading frequently (Springer (2003)). However, since they depend on strong economic assumptions such as the perfect rationality and complete market, and the emissions trading process is not considered, the results must be far from reality (Matsumoto (2007a, 2007c, 2007d)). Therefore, a multi-agent model, which is a bottom-up approach, is applied to reduce such problems and to analyze more properly in this study.

Although I have constructed multi-agent models to analyze international emissions trading under the Kyoto Protocol and the extended Kyoto Protocol, and analyzed the impacts considering some policy frameworks in Matsumoto (2007a, 2007b, 2007c, 2007d, 2007e), some parts of the models are modified to adapt to this analysis.

The rest of this paper is organized as follows. In the second section, the assumptions and model in this study are described. In the third section, the results are shown and discussed. Then, in the final section, some concluding remarks are included.

2 Method

2.1 Assumptions

Assumptions of this analysis are basically based on my previous studies (Matsumoto (2007b, 2007e)). They are summarized as follows.

2.1.1 Agents

In this study, regions (countries), including developed countries, economies in transition, and developing countries, are regarded as agents. Countries are classified into 10 regions as the previous studies. The classification is shown in Table 1. JPN, E_U, KPI, AUS, and USA are developed countries, EFS is economies in transition, and CHN, IND, EEX, and ROW are developing countries. Each region is treated as an independent agent and has an emissions abatement target (see next section).

Table 1 Regions, Emissions Targets (% from the Base Year), and CO_2 Emissions and Emissions Rights (Mt-CO_2) in the Whole Period

	Region	Target	Emissions	Rights
JPN	Japan	94	6 685.4	5 035.8
E_U	European Union	92	17 183.8	14 349.7
KPI	Rest of the OECD countries included in the Annex B of the Kyoto Protocol (e.g. Canada)	94.5	3 760.8	2 456.4
EFS	Economies in transition included in the Annex B of the Kyoto Protocol (e.g. Russia)	98.1	14 118.8	19 949.8
AUS	Australia	108	1 922.6	1 471.1
USA	USA	93	31 239.4	22 417.6
CHN	China	BAU*	26 445.6	26 445.6
IND	India	BAU*	7 751.3	7 751.3
EEX	Energy Exporting Countries (e.g. Indonesia)	BAU*	21 660.5	21 660.5
ROW	Rest of World (e.g. Korea)	BAU*	17 440.8	17 440.8

*Developing countries' targets are the BAU emissions levels.

2.1.2 Targets

In this study, the Kyoto Protocol is considered because it is the only climate change policy adopting emissions trading in the international level. However, only CO_2 emissions out of GHG emissions and CO_2 emissions trading are considered to make some estimations and analysis simpler. Because the Kyoto Protocol is taken into account, the target period is the first commitment period (2008-2012) and each region's emissions target follows the Annex B of the Kyoto Protocol. Although there are countries withdrawing from the Kyoto Protocol and countries without any emissions targets in reality, it is assumed that they also participate in the international emissions trading here. The targets of the former follow the Annex B and those of the latter are the BAU emissions levels.

Each region's BAU CO_2 emissions level in 2008-2012 is estimated referring to Marland et al. (2006) for the emissions data and IEA (2004) for the expected emissions growth rates. Also, the emissions rights assigned to each region are calculated from the Annex B. These assumptions are same as Matsumoto (2007a, 2007b, 2007d, 2007e). They are also shown in Table 1 above.

2.1.3 Fine

A fine is imposed by the dollar per ton of CO_2 ($/t-$CO_2$). If a region cannot accomplish its emissions abatement target in the final year, a fine is imposed against the emissions exceeding the emissions rights. The fine level is very important for each region's decision making, whether to trade or not and whether to abate emissions or not. For example, self-abatement might be beneficial if a region can abate emissions with a unit cost below the fine level and otherwise paying a fine might be beneficial. Moreover, it affects regions when they determine bid or offer price for trade. However, if they cannot abate emissions or obtain emissions rights as they expected, they will pay a fine unanticipatedly.

2.1.4 Marginal Abatement Cost Functions

When each region makes a decision to bid or offer to trade, it has to determine a bid price or offer price[2]. In this study, each region determines the price based on marginal abatement cost (MAC). MAC is calculated using a MAC function and each region has a unique one. Namely, MAC functions of all the regions are different. The functions, which are quadratic, are same as those in the previous studies (Matsumoto

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[2] The details are described in section 2.2.

(2007b, 2007e)) and expressed as Eq.1.

$$p_i = a_i q_i^{\ 2} + b_i q_i \qquad (1)$$

p_i: marginal abatement cost in region i (\$/t-CO_2), q_i: emissions abatement level in region i (Mt-CO_2), a_i and b_i: coefficients for region i.

Table 2 shows the coefficients used in Eq.1. In this study, yearly change in the MAC functions is not considered to make the analysis simple, as well. That is, the same functions are applied every year.

Table 2 Coefficients of Estimated MAC Functions ($p_i = a_i q_i^2 + b_i q_i$)

Region	a_i	b_i
JPN	2.3×10^{-4}	1.2×10^{-1}
E_U	2.4×10^{-5}	3.6×10^{-2}
KPI	3.6×10^{-4}	1.1×10^{-1}
EFS	2.1×10^{-5}	3.0×10^{-2}
AUS	8.7×10^{-4}	1.3×10^{-1}
USA	2.5×10^{-6}	1.1×10^{-2}
CHN	5.1×10^{-6}	5.5×10^{-3}
IND	7.6×10^{-5}	3.4×10^{-2}
EEX	2.3×10^{-5}	3.0×10^{-2}
ROW	3.9×10^{-5}	3.8×10^{-2}

2.2 Multi-Agent Simulation Model

2.2.1 Overview

The flow of this multi-agent simulation model is as follows.

1. Bid or offer (300 opportunities in one year)
2. Trade in the market (300 opportunities in one year)
3. Self-abatement of CO_2 emissions (once in the year-end)
4. Imposition of a fine (once in the end of the last year)

First, each region determines the position and bid or offer for trade in the market. Then, emissions trading is implemented in accordance with the bids and offers. A series of these processes are reiterated 300 times in one year. When a year finishes, each region abates a certain amount of CO_2 emissions. Finally, each region pays a fine if it cannot complete the abatement target.

This model is constructed using the artisoc, a multi-agent simulator developed by

2.2.2 Bid and Offer

The purpose of each region is to abate its CO_2 emissions exceeding its emissions rights and to minimize the cost (or maximize the profit) simultaneously through emissions trading and self-abatement. Because each region is a bounded rational agent, it behaves based on the local information of its own such as the strategies, MAC function, CO_2 emissions, and emissions rights. In addition, it also deliberates on a fine for its decision making.

Bid or offer is the first decision making process for each region. There are two types of regions according to the relation between CO_2 emissions and emissions rights of each region. If a region has emissions rights less than the CO_2 emissions (Type A), it can be either a buyer or a seller of emissions rights. If a region has emissions rights equal to or more than the CO_2 emissions (Type B), on the other hand, it can be a seller of emissions rights. These types are not fixed, but are changeable when the emissions amount and emissions rights are changed due to emissions trading and self-abatement.

Considering the Type A, each region behaves as follows. First, it determines the amount it can abate by itself (potential abatement amount) using its inverse MAC function, Eq.2, given a market price in the previous period. Eq.2 is obtained from Eq.1.

$$pq_i = \frac{-b_i + \sqrt{b_i^2 + 4a_i pmp}}{2a_i} \tag{2}$$

pq_i: potential abatement amount in region i (Mt-CO_2), pmp: market price in the previous period (\$/t-CO_2).

Then, the potential abatement amount is compared with the amount it has to abate within a year (obligatory abatement amount)[3]. If the potential abatement amount is smaller than the obligatory abatement amount, the region becomes a buyer and demands a certain amount of emissions rights. If the potential abatement amount is larger, on the other hand, the region becomes either a seller or a buyer, and supplies or demands a certain amount of emissions rights. In the former case, the region selects a strategy from a set of strategies to determine a bid price, which is calculated based

[3] It is assumed that each region abates the excess emissions equally in the remaining years.

on MAC calculated from Eq.1 using the obligatory abatement amount as q_i. The set includes 10 strategies and each of them represents a range of bid prices in percentage (1-10%). Then, using it, a bid price is determined from Eq.3[4]. However, if the fine level is smaller than MAC in the equation, the fine level is used instead of the MAC in this process. It is because all the MAC functions are increasing functions and the region would be able to reduce the cost by paying a fine instead of self-abatement even if it failed to trade as a result.

$$bp_i = p_i \times \frac{100 - br_{is}}{100} \tag{3}$$

bp_i: bid price in region i (\$/t-CO_2), br_{is}: a range of bid prices of selected strategy s in region i (\$/t-CO_2).

In the latter case, as the region selects a strategy from a (different) set of strategies, it is not only to determine a bid or offer price but also to determine the position. That is, each strategy is composed of a range of bid or offer prices and a position (to be a buyer or a seller). The set includes 20 strategies. When a region becomes a seller, the offer price is determined from Eq.4.

$$op_i = p_i \times \frac{100 + or_{is}}{100} \tag{4}$$

op_i: offer price in region i (\$/t-CO_2), or_{is}: a range of offer prices of selected strategy s in region i (\$/t-CO_2).

When it becomes a buyer, on the contrary, the bid price is determined from Eq.3. Besides, if the fine level is smaller than the MAC, it is used instead of the MAC as described above.

The way to select a strategy from the set is based on the evaluation value on each strategy. The evaluation value indicates how the strategy is superior and one strategy is selected randomly with the probability proportionally to the evaluation value. It is updated as a result of trade by reinforcement learning. The detail is explained in section 2.2.3[5].

[4] By doing so, each region intends to attain its abatement target cheaper than it abates by itself.

[5] This way of selection of strategies and evaluation is a revised version of Kimura and Oda (2002) and Oda et al. (2003), and the similar method is also used in Matsumoto (2007a, 2007b, 2007c, 2007d).

In both cases, the bid or offer amount is determined based on difference between the potential abatement amount and obligatory abatement amount by assuming that the same amount will be traded in the remaining opportunities (steps) as Eq.5, except the random term.

$$bom_i = rnd \times \frac{|oq_i - pq_i|}{rt} \tag{5}$$

bom_i: bid or offer amount in region i (t-CO_2), oq_i: obligatory abatement amount in region i (t-CO_2), rt: remaining trade opportunities, rnd: random value to control bid or offer amount.

Next, considering the Type B, each region only can be a seller and the bid amount is calculated from Eq.5 as well as Type A. Then, the bid price is set randomly between \$1/t-CO_2 and \$15/t-CO_2[6]. In this manner, Type B regions do not use strategies to determine their behavior.

When all regions determine the position, bid or offer price, and bid or offer amount, all the bid and offer messages are sent to the market.

2.2.3 Trade

In this model, double auction is adopted as a trade method.

When bids and offers from all regions are gathered in the market, trade is started. It is implemented from an order with the lowest offer price and that with the highest bid price as long as both sides of orders exist and the lowest offer price is not higher than the highest bid price. One trade price (equilibrium price) is determined for each step as the intersection point of the supply curve developed from the gathered offers with the demand curve developed from the gathered bids. Therefore, it is not always true that all bids and offers are traded.

Each time a trade is succeeded, the evaluation values on the selected strategies are updated for both seller and buyer of Type A as mentioned above. Since success of trade means success of the selected strategies, the evaluation values are increased based on the difference between the bid or offer price and trade price, and the proportion of the traded amount to the bid or offer amount as Eq.6. Originally, all evaluation values are 100.

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[6] Because the Type B regions' obligatory abatement amounts are zero, Eq.4 is not suitable for them.

$$ev_{t+1} = ev_t + |tp_t - bop_{it}| \times \frac{tm_{it}}{bom_{it}} \tag{6}$$

ev_t: evaluation value in step t, tp_t: trade price in step t (\$/t-CO_2), bop_{it}: bp_i for buyers or op_i for sellers in step t (\$/t-CO_2), tm_{it}: traded amount in region i in step t (t-CO_2), bom_{it}: bom_i in step t (t-CO_2).

2.2.4 Self-Abatement

Self-abatement of CO_2 emissions is the second decision making process for each region. This model assumes that each region abates its CO_2 emissions exceeding the emissions rights it has by itself after emissions trading, and it is implemented every year. This process is very different from the previous studies (Matsumoto (2007a, 2007b, 2007c, 2007d, 2007e)). Although it is assumed that all regions (can) achieve the abatement targets and the CO_2 emissions become equal to the emissions rights in the final year by self-abatement in the previous studies, this model is modified so that there is possibility that regions do not (cannot) attain the targets in this study so as to analyze the effects and influence of the fine appropriately. Basically, each region intends to abate same amount of emissions in the remaining years through emissions trading and self-abatement. Therefore, the fundamental self-abatement amount is set as Eq.7.

$$sa_i = \frac{emit_i - rght_i}{ry} + trad_i \tag{7}$$

sa_i: fundamental self-abatement amount in region i (t-CO_2), $emit_i$: total CO_2 emissions in region i (t-CO_2), $rght_i$: total emissions rights in region i (t-CO_2), ry: remaining years, $trad_i$: net amount of emissions rights sold by region i in the year (t-CO_2).

However, if the fundamental self-abatement amount is too large, the assumption that the region can abate the amount is inappropriate. Therefore, a certain fixed amount it can abate in a year (the limit amount, la_i) is determined in advance. In addition, since a fine is introduced and each region makes a decision about self-abatement depending on the fine level, it is natural to assume that it does not abate emissions above the amount corresponding to the fine level (fa_i).

To summarize the above description, the self-abatement amount is set as follows: sa_i if "$fa_i > la_i$ and $la_i > sa_i$" or "$la_i > fa_i$ and $fa_i > sa_i$"; la_i if "$fa_i > sa_i$ and $sa_i > la_i$" or "$sa_i > fa_i$ and $fa_i > la_i$"; fa_i in other cases.

Since the purpose of each region is to abate emissions so as to equalize its emissions to its emissions rights, this process is only related to the Type A.

After this process, a fine is imposed on each region whose emissions are larger than the emissions rights as the way described in section 2.1.3.

3 Results and Discussions

In the analysis, fines from \$0/t-CO_2 to \$100/t-CO_2 are considered. The above model is run for 30 times for each fine level. Then, the results obtained from the simulations are processed statistically.

First, the influence of a fine on emissions trading itself is described.

Fig.1 shows the overall picture of emissions trading. As Fig.1-A shows, the total trade amount tends to be higher as the fine level increases and the amount becomes almost the same level when the fine level attains \$8/t-CO_2. As Fig.1-B shows, the total trade value also tends to be higher as the fine level increases and the value becomes almost the same when the fine level attains \$8/t-CO_2 as well. As Fig.1-C shows, the average trade price also tends to be higher as the fine level increases and the price becomes almost the same when the fine level attains \$9/t-CO_2. Moreover, it is also revealed that the price never becomes higher than the fine level in all the cases. It is due to each region's decision making process in which fines are considered. Then, as Fig.1-D shows, the trade frequency is almost the same despite the fine level as long as trade is implemented in the market. Trade is not implemented when the fine level is less than \$1/t-CO_2 and implemented when it is higher than that.

Fig.2 shows some examples of time series of trade. Each graph in the figure shows fluctuation of the trade amount and trade price in each step. When the fine level is low like the case of Fig.2-A, the trade price hardly fluctuates at a bit below the fine level. On the other hand, the trade amount fluctuates widely and it tends to increase gradually as time passes. As the fine level increases, the fluctuation range of the trade price becomes wider and that of the trade amount becomes narrower. Concerning the cases in Fig.2, standard deviation of the trade price is 17.3 and that of the trade amount is 0.6 when the fine level is \$5/t-CO_2 (Fig.2-A), that of the trade price is 8.8 and that of the trade amount is 1.6 when the fine level is \$8/t-CO_2 (Fig.2-B), that of the trade price is 5.2 and that of the trade amount is 4.0 when the fine level is \$15/t-CO_2 (Fig.2-C), and that of the trade price is 4.7 and that of the trade amount is 4.3 when the fine level is \$50/t-CO_2 (Fig.2-D). The reason that the fluctuation range of the trade price is narrow when the fine level is low is that the trade price is controlled by the sufficiently-low fine level which plays a role as the threshold even though the intrinsic trade price is higher. Then, as the fine level becomes higher, the role as the threshold

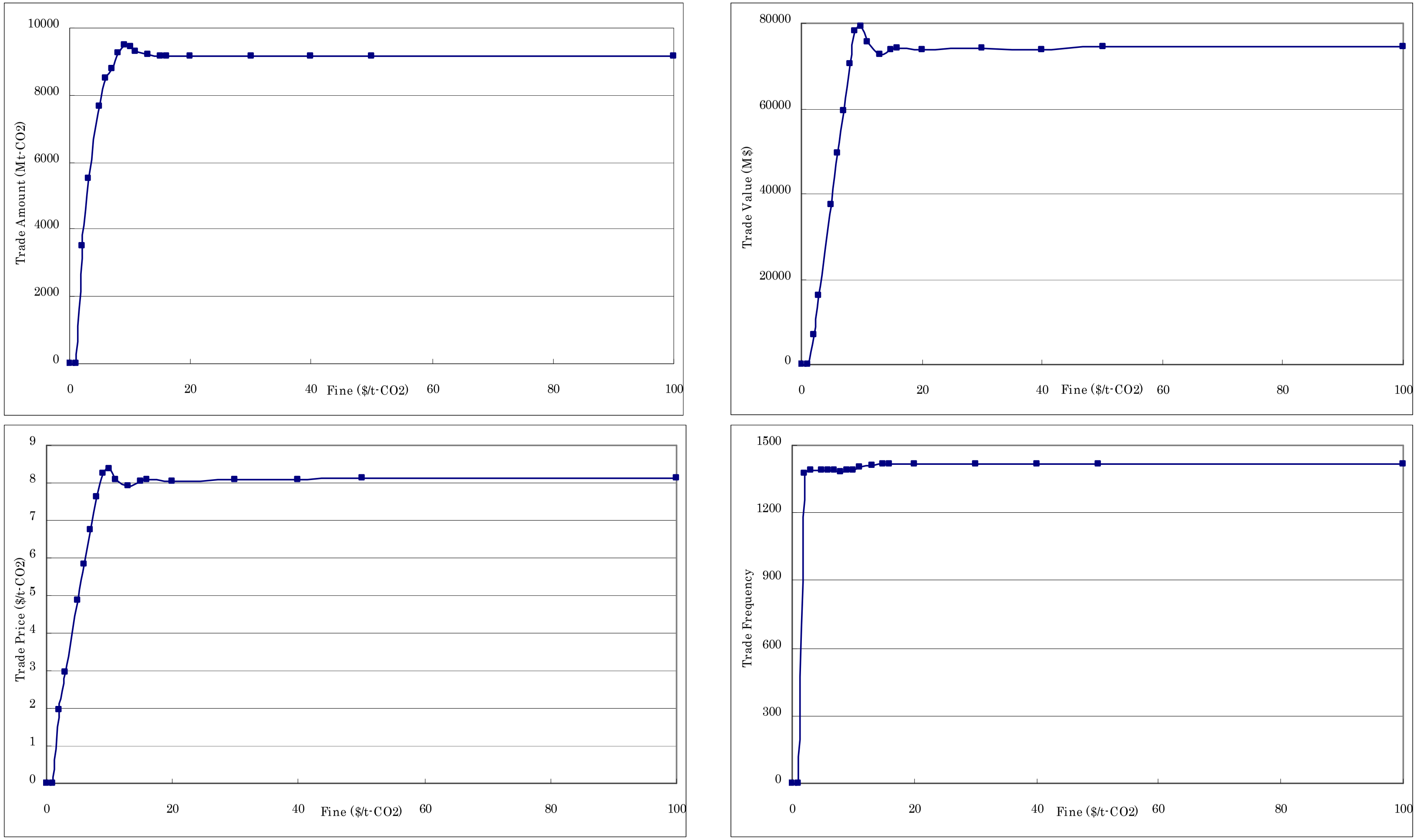

Fig.1 Overall Picture of Emissions Trading by Fine Level (A (Upper Left): Total Trade Amount, B (Upper right): Total Trade Value, C (Lower Left): Average Trade Price, D (Lower Right): Trade Frequency)

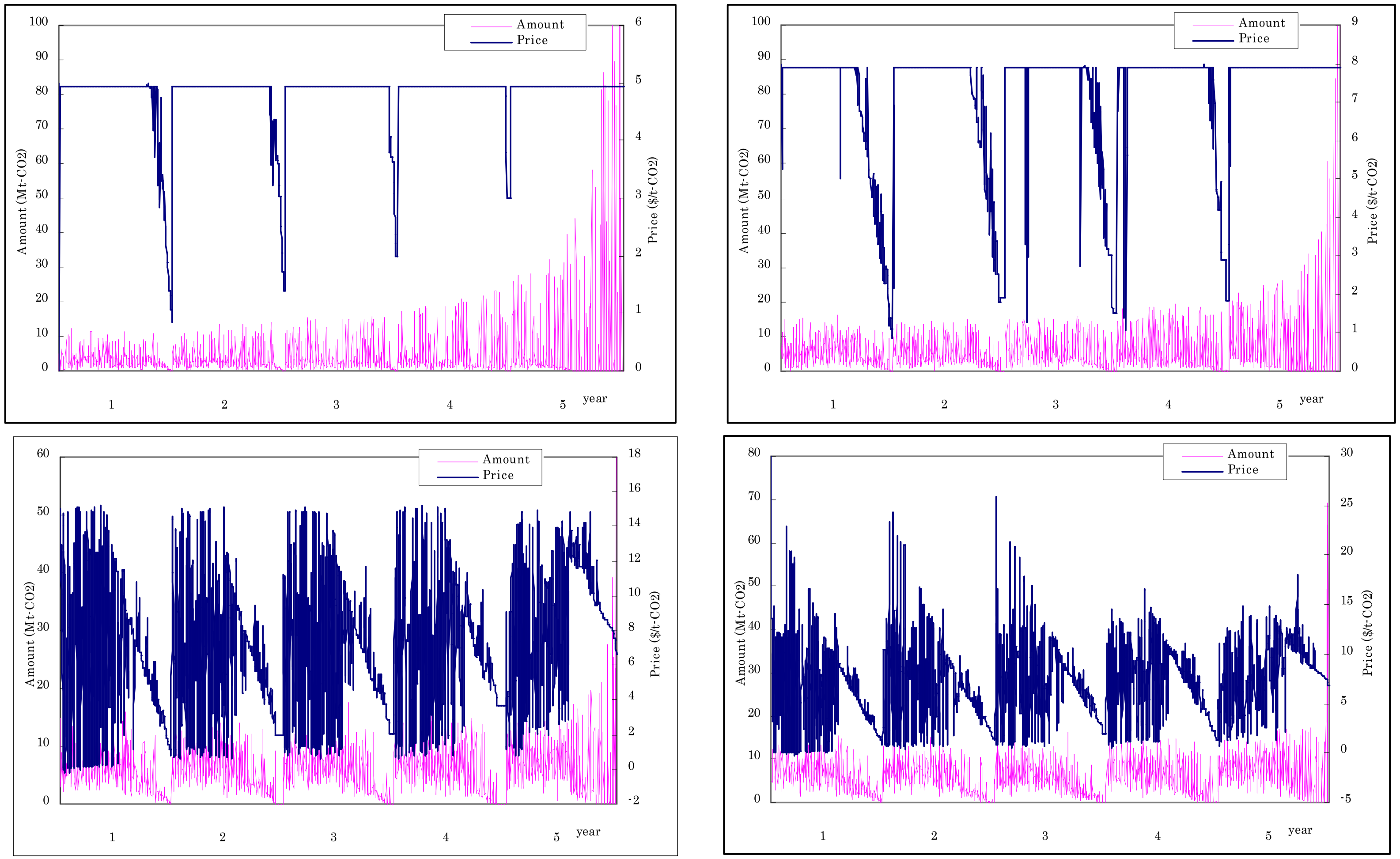

Fig.2 Examples of Time Series of Trade (A (Upper Left): $5/t-CO_2$ Fine, B (Upper Right): $8/t-CO_2$ Fine, C (Lower Left): $15/t-CO_2$ Fine, D (Lower Right): $50/t-CO_2$ Fine)

gets smaller and a wide range of the price can be realized. Although the price fluctuates to a greater or lesser extent, it never exceeds the fine level. Concerning the fluctuation range of the trade amount, the reason that the range is wide when the fine level is low is that a large amount of trade can occur due to the low price level.

Next, the effects and influence of the fine on each region and the whole world are described.

Fig.3 shows the costs to abate emissions (negative values mean the benefits). Developed countries suffer costs due to self-abatement and purchase of emissions rights, while economies in transition and developing countries make a profit due to sellout of emissions rights[7]. As Fig.3-A shows the total costs including the fine values, they tend to be larger as the fine level increases. Depending on regions, the costs or the benefits are almost the same when the fine level is higher than about \$8-9/t-CO_2. A breakdown of the costs or the benefits is indicated in Fig.3-B-Fig.3-D. As these figures show, the trade costs account for a large proportions of the total costs except the cases the fine level is very low where the fine values account for a large proportion. Concerning the self-abatement costs (Fig.3-B) and trade costs (Fig.3-C), they tend to be larger as the fine level increases as well as the total costs. Significance of self-abatement to achieve the emissions abatement targets increases as the fine level increases and that of emissions trading is largest when the fine level is about \$10/t-CO_2. Concerning the fine values (Fig.3-D), on the other hand, they first become larger as the fine level increases, but the tendency is reversed after that and they finally become zero when the fine level attains \$10/t-CO_2. The fine value on each region is determined by the fine level and noncompliant emissions amount (see Fig.4-A), and its decision making about emissions trading and self-abatement is influenced by increase in the fine level which causes to raise the trade price and to increase each region's cost. The above results are due to such multiple factors.

Fig.4 shows each region's abatement behavior. As Fig.4-A shows, the noncompliance amounts seen in developed countries tend to be lower as the fine level increases[8]. It is because paying a fine is a cheaper way than abating by themselves or buying emissions rights when the fine level is low since they take it into consideration when making a decision. As the proof, the trade and self-abatement amounts increase as the fine level increases as shown in Fig.4-B and Fig.4-C, respectively.

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[7] It is because economies in transition has excessive emissions rights, so-called hot air, and developing countries do not have to abate emissions initially and can abate emissions very cheaply.

[8] In this study, economies in transition and developing countries always achieve their abatement targets.

Fig.4-A indicates one more important aspect. That is, the lower the fine level, the larger the noncompliance amount and the larger the environmental influence as a result in the case the fine level is lower than \$10/t-CO_2. When it is \$0/t-CO_2, no trade and no self-abatement occur at all[9].

The results of this study can be summarized as follows. Concerning the influence on the emissions trading market, the trade price and amount increase up to a point as the fine level increases, and the larger the fine level, the wider the fluctuation of the trade price and the narrower that of the trade amount. Concerning the influence on each region, the costs to achieve the emissions targets for developed countries and the whole world tend to increase by increasing the fine level. Namely, a smaller fine is better from the cost perspective for the regions. On the contrary, if it is too small, the emissions abatement targets cannot be achieved and it is a tremendously serious matter. However, it is not true that an extremely high-level fine is appropriate since a certain fine level is enough to achieve the targets and such a high-level fine will be more difficult to be accepted when introducing. In this regard, however, if additional systems such as use of the collected fines to additional emissions abatement and carry-over of the noncompliance amounts to the next commitment period (if existing) are institutionalized, the influence of noncompliance can be reduced although some delay appears.

Because there are some aspects which are determined arbitrarily in the model such as a range of bid and offer prices, it can be said that the results have important meaning to understand the relative relations among the fine level, decision making processes, and effects and influence of the fine.

4 Concluding Remarks

In this article, the effects and influence of a fine system in emissions trading on the trade, regions (countries), and emissions abatement were investigated quantitatively. Since it is important to eliminate some strong economic assumptions and consider the emissions trading process, a multi-agent simulation model was applied for the analysis. From the analysis, it was revealed that emissions trading, the costs and benefits on the regions, and compliance of the emissions abatement targets were strongly affected by the fine level up to a point, but these tendencies were stabilized after attaining a certain level. Consequently, it was mentioned that a certain fine level was necessary to achieve the abatement targets, but a fine with too high level

[9] In a practical sense, even though any penalties exist, self-abatement and emissions trading will occur due to political responsibility, social responsibility, and so on.

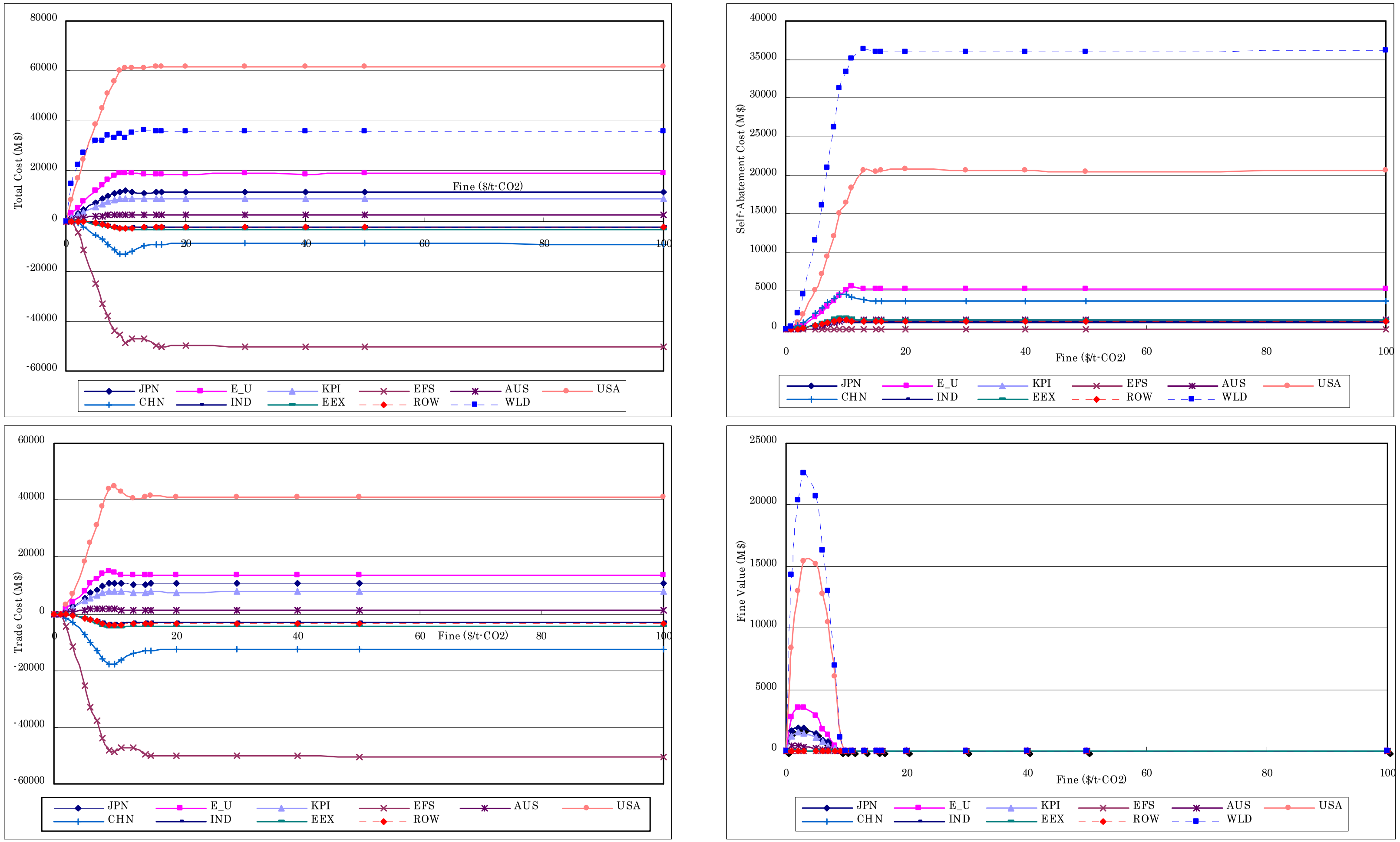
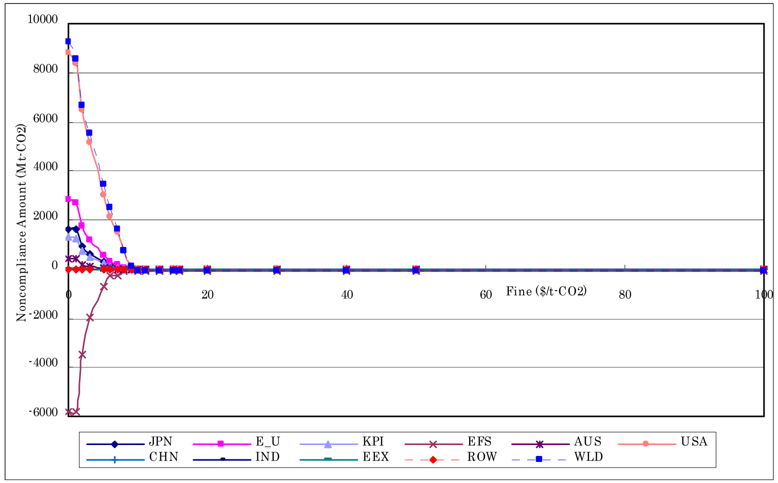
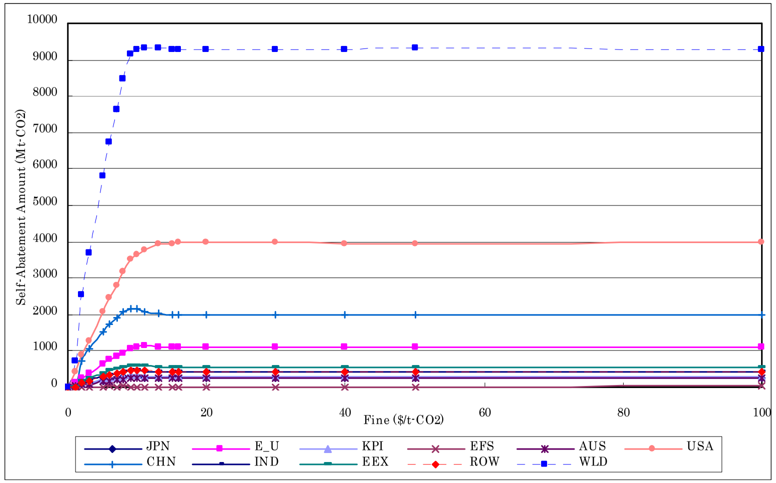


Fig.3 Costs for Abatement (A (Upper Left): Total Costs, B (Upper Right): Self-Abatement Costs, C (Lower Left): Trade Costs, D (Lower Right): Fine Values)

*WLD: World Total





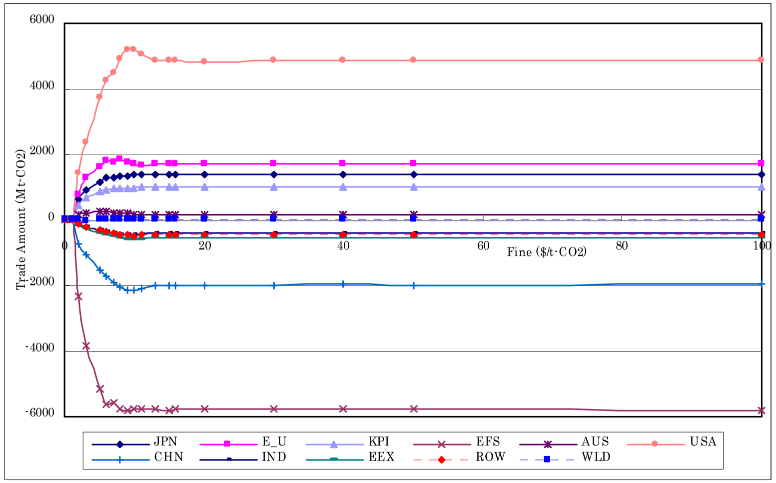


Fig.4 Emissions Abatement Behavior (A (Upper): Noncompliance Amounts, B (Lower Left): Self-abatement Amounts, C (Lower Right): Trade Amounts)

*WLD: World Total

was unnecessary.

For the future investigation, it is necessary to reveal influence of schemes likely to be strongly related to GHG emissions trading such as penalties other than a fine, a sort of participants (agents), and restriction of degree of dependence on emissions trading, and to study in order to construct a better trading system. Moreover, it is also important to examine more precisely about agents' decision making system.

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