Agent-based Simulation of Emissions Trading: Evaluation of Non-compliance Penalty and Commitment Period Reserve

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Abstract: The Kyoto Protocol adopted in 1997 has three flexible mechanisms in order to prevent the earth from global warming. One of them is emissions trading. Saijo and Kusakawa (2002) designed some trading systems and conducted emissions trading experiments in order to evaluate them. Such human-based experiments, however, have several basic problems. First, any single experimental result might depend on a particular set of subjects. Second, a considerable number of repetitions are needed to have statistically robust results. In order to avoid these drawbacks, we construct an agent-based emissions trading simulation model that does not use human subjects, but artificial computer agents. It is relatively easy to repeat many simulations with many different parameters when we use the simulation method. Our focus is learning through the trading and we employ the Genetic Algorithm (GA). We evaluate two trading designs: the penalty against non-compliance and the Commitment Period Reserve (CPR) adopted in the Marrakesh accords. The former has a question how much penalty should be imposed on countries with non-compliance. We have two cases. Case 1 is that the penalty is fixed, and Case 2 is that the penalty depends on the average contract price of emissions permits. We found that in Case 1 all countries tried to comply with their target, while in Case 2 demand countries had some incentive not to comply the protocol on purpose. The latter has a question whether we should adopt the CPR or not to the emissions trading system. We found that the CPR dared not be adopted because we confirmed that it had no significant effect.

Keywords: *Emissions trading; Agent-based simulation; Genetic Algorithm; Commitment Period Reserve*

1. INTRODUCTION

At the third Conference of Parties (COP3) to the United Nations Framework Convention on Climate Change, held in Kyoto in December 1997, the Kyoto Protocol was adopted. The Protocol establishes national emission targets for greenhouse gases (GHGs) for developed countries and economies in transition. In effect the Protocol calls for an overall emissions reduction of 5.2% from 1990 levels, with Japan for example to attain 94% of 1990 emissions, USA 93%, EU 92%, and Russia 100%, during the period 2008 to 2012. In order to achieve this goal the use of Kyoto mechanisms, which include international emissions trading, joint implementation, and the Clean Development Mechanism, was authorized. Detailed design of the mechanisms from an economics viewpoint is important. Our focus is on emissions trading.

Saijo and Kusakawa (2002) designed some trading systems and conducted emissions trading experiments in order to evaluate them. Such human-based experiments, however, have several basic problems. First, any single experimental result might depend on a particular set of subjects. Second, a considerable number of repetitions are needed to have statistically robust results.

In order to avoid these drawbacks, we construct an agent-based emissions trading simulation model that does not use human subjects, but artificial computer agents. It is relatively easy to repeat many simulations with many different parameters when we use the simulation method. This paper describes the evaluation of two trading designs using the constructed simulation. One is the penalty against non-compliance and the other is the Commitment Period Reserve (CPR) adopted in the Marrakesh accords.

2. EMISSIONS TRADING SIMULATION MODEL

In this study, the number of participating agents is 10 (RU, EER, USA, UK, FR, GER, RestEU, CAN, AU_NZ, JPN). All agents aim to attain their target by domestic reduction and emissions trading of each year.

2.1. Reduction technology

The technology of actual greenhouse gases emissions reduction is characterized by two features: investment time lag and investment irreversibility. Investment time lag means that countries cannot reduce their emissions immediately after the decision to do so. Investment irreversibility means that although countries can increase capital level they cannot reduce it.

In order to introduce these two features, we apply diminishing return scale emissions reduction at year t (=2008,…,2012):

$$Q(t) = AV(t)^{\alpha} K(t)^{\beta}$$

where *Q(t)* is the level of emissions reduction at year t, *V(t)* the level of variable input at year t, *K(t)* the capital level at year t, and A, α and β the technical parameter different for each country. Long-run marginal abatement cost for each country at year t (*LMC(t)*) and Short-run marginal abatement cost (*SMC(t)*) are the following curves:

$$LMC(t) = \left[A(t)^{-1}\alpha(t)^{-\alpha(t)}\beta(t)^{-\beta(t)}r(t)^{\beta(t)}w(t)^{\alpha(t)}Q(t)^{1-\alpha(t)-\beta(t)}\right]^{\frac{1}{\alpha(t)+\beta(t)}}$$

$$SMC(t) = A(t)^{\frac{1}{\alpha(t)}}K(t)^{-\frac{\beta(t)}{\alpha(t)}}\alpha(t)^{-1}w(t)Q(t)^{-1+\frac{1}{\alpha(t)}}$$

where r(t) is the rental cost per unit and w(t) the variable cost per unit.

In this study, we peg r(t) and w(t) at a price of $1, α at 0.4, and β at 0.1 and each countries' A(t) at the each value which is derived by using the expected data of emissions and marginal abatement cost in International Energy Outlook 2000 and European Union Energy Outlook to 2020. Decided *LMC* is shown in Figure 2-1.

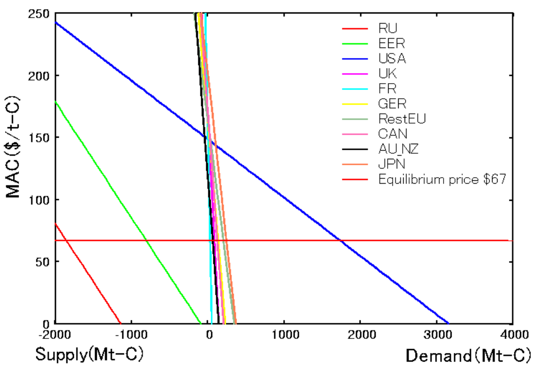

Figure 2-1. LMC

2.2. Decision-making algorithm

At the start of simulation, all agents firstly decide the amount of their 2008's domestic reduction. Secondly, they offer their bids and trade for 5 times. We adopt the uniformed price auction as the method of trading. In 2009~2012 they make decisions in the same way. After finishing 2012's trading, each agent's total cost is calculated.

Each agent strengthens his decision as his total cost becomes cheaper. We use Genetic algorithm (GA) as a learning algorithm. The parameters of GA are shown in Table 2-2.

Table 2-2. Parameters of GA

Generation number	Population number	Gene length	Chiasma rate	Mutation rate
10000	100	475	60%	5%

3. EVALUATION OF NON-COMPLIANCE PENALTY

In order to design emissions trading market, it is important how much penalty should be imposed on countries with non-compliance. We have two cases. Case 1 is that the penalty is fixed, and Case 2 is that the penalty depends on the average contract price of emissions permits. We simulated the two cases and evaluate the penalty.

3.1. Results (Case1)

We simulated the 8 cases (the penalty price was 250, 200, 150, 130, 120, 110, 100, 50($/t-C)). We simulated each case for 10 times. The result of the contract prices is shown in Figure 3-1, where the horizontal axis represents the penalty. When the penalty is 100($/t-C), the contract price is nearest the equilibrium price 67($/t-C). And the contract price becomes more expensive as the penalty becomes more expensive. That is because demand countries have more incentive to buy though the contract price gets up, as the penalty becomes more expensive.

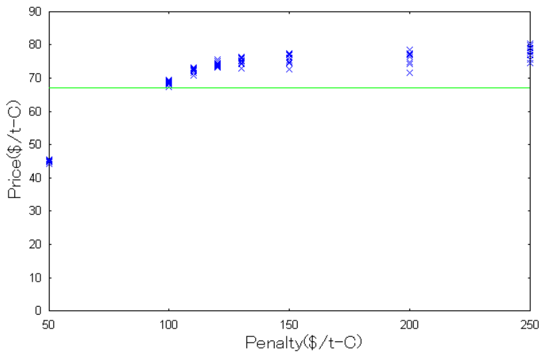

Figure 3-1. Contract price

The result of the excessive reductions is shown in Figure 3-2. When the penalty is more than 120($/t-C), the excessive reduction is positive, in short, the target of Kyoto Protocol is attained.

And the excessive reduction becomes smaller as the penalty becomes cheaper. That is because demand countries try to reduce more emissions for fear of paying the penalty, as the penalty becomes more expensive.

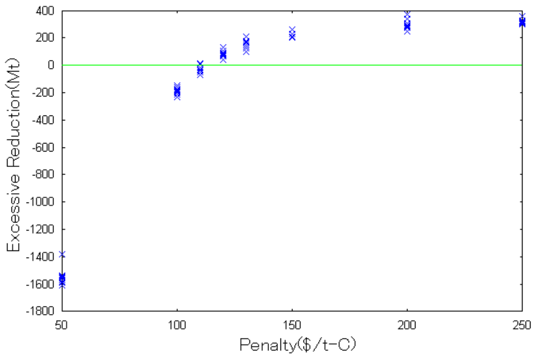

Figure 3-2. Excessive reduction

The results of the average contract prices, the excessive reductions and the economical efficiency are shown in Table3-1. Economical efficiency is defined as the ratio of the sum of surplus extracted in the simulation to the sum of surplus extracted at competitive equilibrium. When the penalty is expensive, the economic efficiency becomes high. When the penalty is 120($/t-C), the economical efficiency is maximized.

Table 3-1. Average contract price/Excessive reduction

Penalty ($/t-C)	Contract price ($)	Excessive reduction (Mt)	Economical efficiency (%)
250	77.6	322	75
200	76.1	299	75
150	75.8	221	76
130	75.1	153	78
120	74.0	83	78
110	72.2	-29	77
100	68.6	-188	74
50	44.9	-1550	45

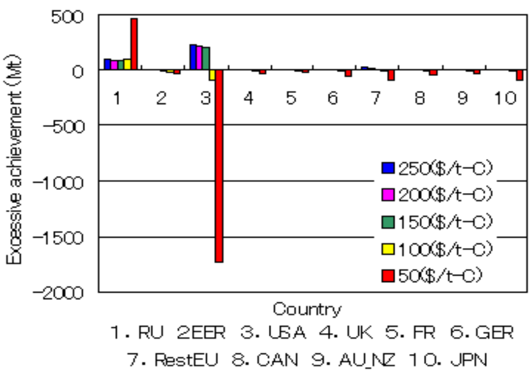

Figure 3-3. Excessive achievement

The result of each country's excessive achievement was shown in Figure 3-3,where the horizontal axes represented each country. All countries tried to comply with their target when the penalty was expensive.

3.2. Results (Case2)

We simulated 8 cases (the penalty rate is 5, 3, 2, 1.9, 1.8, 1.7, 1.6, 1.5). We simulated each case for 10 times. The result of the contract prices is shown in Figure 3-4, where the horizontal axis represents the penalty rate. The penalty rate is defined as the ratio of the penalty to the average contract price. In the same of Case1, The contract price becomes more expensive as the penalty rate becomes higher. In addition, when the penalty rate is less than 1.8, the contract price severely drops.

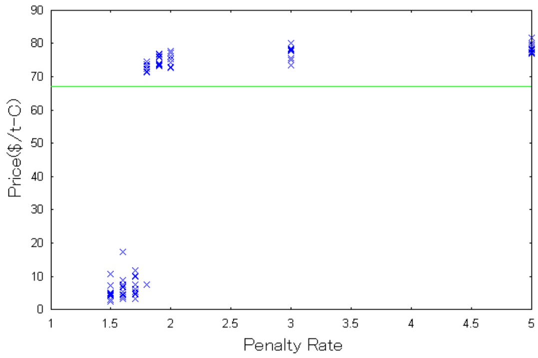

Figure 3-4. Contract price

The result of the excessive reductions is shown in Figure 3-5. In the same of Case1, The excessive reduction becomes smaller as the penalty rate becomes higher. In addition, when the penalty rate is less than 1.8, the excessive reduction severely drops.

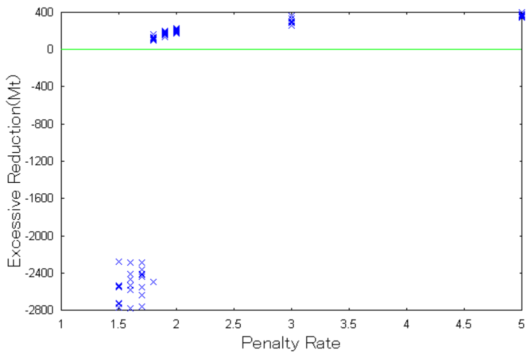

Figure 3-5. Excessive reduction

The results of the average contract prices, the excessive reductions, and the economical efficiency are shown in Table 3-2. When the penalty rate is more than 1.9, the economical efficiency becomes high, but when it is less than 1.8, the economical efficiency severely drops.

Table 3-2. Average contract price/ Excessive reduction

Penalty rate	Contract price ($)	Excessive reduction (Mt)	Economical efficiency (%)
5	78.7	368	76
3	77.3	306	76
2	75.6	195	76
1.9	74.7	170	75
1.8			
1.7	6.9	-2528	6
1.6	6.9	-2611	4
1.5	5.1	-2681	0

The contract price and the excessive reduction at the penalty rate 1.8, where both the high efficiency and the low efficiency are observed, is shown in Figure 3-6 and Figure 3-7. The horizontal axis represents the simulation times. Once in several times the contract price and the excessive reduction severely drops. In other words, if the penalty depends on the average contract price of emissions permits, there is the possibility that the market would fail.

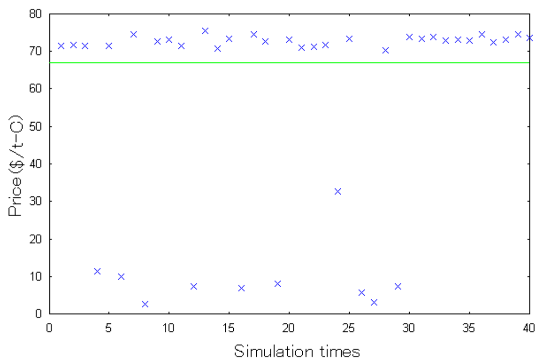

Figure 3-6. Contract price

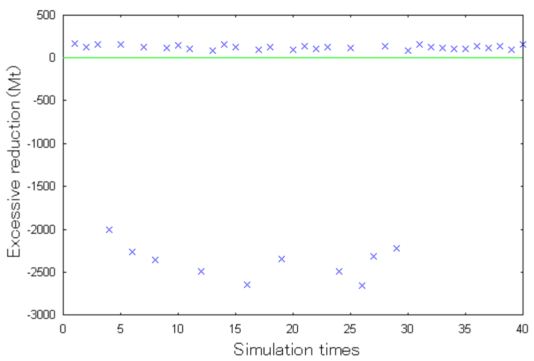

Figure 3-7. Excessive reduction

The result of the each country's excessive achievement is shown in Figure 3-8. Demand countries' excessive achievement severely drops when the penalty rate is less than 1.8. That is because of the following set of Demand countries action.

1. Decrease a price or a volume on order on the trading period that the contract price is expensive
2. Average contract price gets down
3. Penalty gets down
4. Decrease the amount of domestic reduction

In short, Demand countries have a possibility not to comply the protocol on purpose.

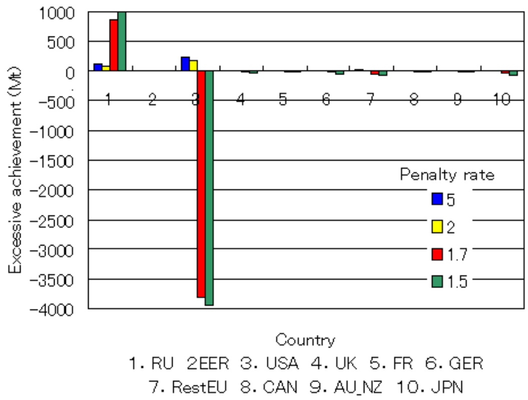

Figure 3-8. Excessive reduction

3.3. Summary

We found that In Case 1 the penalty was fixed at expensive price, all countries tried to comply with their target. We also found that in Case 2 the penalty depended on the average contract price of emissions permits, demand countries had some incentive not to comply the protocol on purpose.

4. EVALUATION OF THE COMMITMENT PERIOD RESERVE (CPR)

The article 17 of Kyoto Protocol says, "(…) The Parties included in Annex B may participate in emissions trading (…). Any such trading shall be supplemental to domestic actions (…)". As the supplemental proposal, EU proposed the Restriction on the perchase of permits in 1999. This proposal, however, was rejected because USA and Japan objected it.

Since USA declared not to ratify Kyoto Protocol in 2001, most powerful country became Russia. Upon that, EU proposed the restriction of the sale of permits. That is called for Commitment Period

Reserve (CPR). The CPR is expressed in Marrakech Accord as follows, "Each party (…) shall maintain (…) a commitment period reserve which should not drop below 90 percent of the party's assigned amount (…), or 100 percent of five times its most recently reviewed inventory, whichever is lowest".

The change of the price by adopting the CPR is shown in Figure 4-1, where the horizontal axis represented the quantity and the vertical axis represented the price. If the price is determined as the point where the supply curve intersects the demand curve, the price is P' under no restriction. The price, however, goes up to P'' under strict restriction of the CPR. Thus, supply countries can control the price by using the restriction, so the CPR is said to be advantage for supply countries.

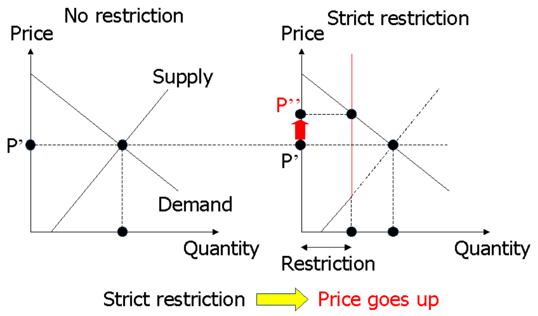

Figure 4-1. Restriction of the sale of permits

In this study, we simulated the two cases, one was that the CPR was not adopted and the other was the case that it was adopted.

4.1. Result

We simulated 5 cases that the penalty price was 250, 200, 150, 100, and 50 ($/t-C). We simulated each case for 10 times. The results of the average contract price and the average trading volume are shown in Table 4-1. We observe the CPR effect, which is the price goes up and the trading volume decreases.

Table 4-1. Contract price/Trading volume

Penalty ($/t-C)	Contract price ($) Non-CPR	Contract price ($) CPR	Trading volume (Mt) Non-CPR	Trading volume (Mt) CPR
250	77.6	80.1	2029	1965
200	76.1	77.1	2009	1948
150	75.8	76.7	2027	1935
100	68.6	68.8	1920	1955
50	44.9	44.2	1198	1209

The results of the average excessive reduction and the economic efficiency are shown in Table 4-2. The excessive reduction and the economic efficiency are scarcely changed by adopting the CPR.

Table 4-2. Excessive reduction/Economic efficiency

Penalty ($/t-C)	Excessive reduction (Mt) Non-CPR	Excessive reduction (Mt) CPR	Economic efficiency (%) Non-CPR	Economic efficiency (%) CPR
250	322	327	75	76
200	299	298	75	76
150	221	211	76	78
100	-188	-179	74	76
50	-1550	-1559	45	46

The result of each country's cost in two cases of penalty 250 ($/t-C) is shown in Figure 4-2. Supply countries' benefits put on a little gain and demand countries' costs slightly increase by adopting the CPR due to the up of the contract price, but the change is a little bit.

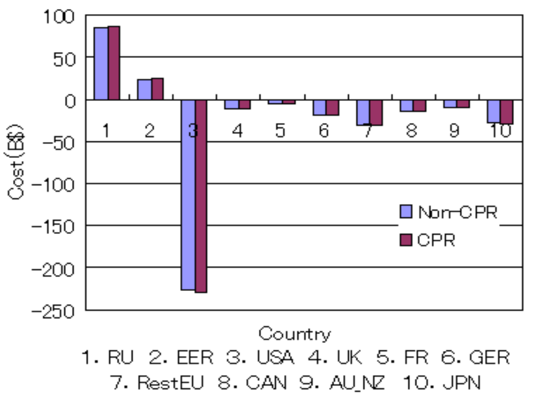

Figure 4-2. Each country's cost

The result of each country's excessive achievement in two cases of penalty 250 ($/t-C) is shown in Figure 4-3. Supply countries' excessive achievements a little increase due to the restriction of the CPR. This change scarcely has any effect because demand countries costs are nearly the same. While, Demand countries' excessive achievements are nearly the same. For that reason, we found that the CPR has no significant effect to economical efficiency, excessive reduction and each country's excessive achievement.

For that reason, we found that the CPR had no significant effect to the economical efficiency, the excessive reduction and each country's excessive achievement.

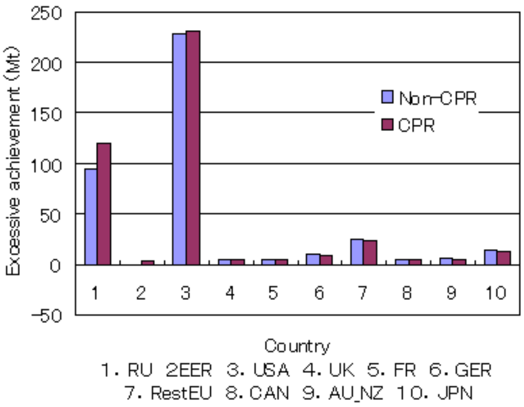

Figure 4-3. Each country's excessive achievement

4.2. Summary

We realized that adopting the CPR has no significant effect in terms of both an environmental view and an economical view.

Saijo and Kusakawa (2002) correspondingly confirmed that adopting the CPR was no significant effect through their experiments.

Consequently, we found that, considering the monitoring cost, we dared not to adopt the CPR to emissions trading system.

5. CONCLUSION

We constructed the agent-based simulation model of emissions trading based on Genetic algorithm. By using the agent-based simulation model, we evaluated the penalty against non-compliance and the Commitment Period Reserve.

First, we found that in Case 1 the penalty was fixed at expensive price, all countries tried to comply with their target. For that reason, the economic efficiency and the excessive reduction became high. We also found that in Case 2 the penalty depends on the average contract price of emissions permits, demand countries had some incentive not to comply the protocol on purpose. For that reason, the economic efficiency and the excessive reduction became low.

Second, we found that that adopting the CPR has no significant effect because the excessive reduction, the economic efficiency, and each country's excessive achievement were scarcely changed by adopting the CPR. Hence, the CPR dared not be adopted considering the monitoring cost.

In addition, the agent-based simulation could be an effective tool to evaluate emissions trading designs.

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