

Very Preliminary!!

Emissions Trading Experiments:  
Investment Uncertainty and Liability

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## Executive Summary

Emissions trading is regarded as a cost-effective tool to reduce greenhouse gases. For example, if the reduction cost of one unit of greenhouse gases (GHGs) in Japan is 10 and the cost in Russia is 1, and if each country must reduce one unit of GHGs respectively, then the total cost would be 11. On the other hand, if Russia reduces two units, then the cost would be 2. That is, Japan pays an amount of money between 1 and 10 to Russia, and asks Russia to reduce one unit of GHGs in return; this is called emissions trading.

The sum of benefit and profit from emissions trading in the above example is 9 ( $=10+1-2$ ). If, for example, 0.6 units are traded then the cost to Russia is  $1+0.6=1.6$  and the domestic reduction cost to Japan is  $(1-0.6)10=4$ . Therefore, the sum of benefit and profit for both countries becomes  $5.4(=11-1.6-4)$ . Since the maximum sum of benefit and profit is 9, the efficiency of 0.6 units of trading becomes  $5.4/9=60\%$ . One of our concerns in emissions trading experiments is to determine what type of institutions would result in high efficacy.

The above example describes simple trading. In order to attain further reductions, it is necessary to introduce reduction investment such as new instruments. "When" and "how" reduction investment is carried out is an important decision variables as well as trading. In order to understand how emissions trading really works, we conducted three major experiments.

### (1) Experiment 1

We conducted 13 sessions using 78 subjects in 1998. This experiment assumes reversible investment. Reversible investment means that even after an investment decision, the decision maker can stop the investment and return to the original plans. Under this rather unrealistic assumption, we observed that emissions trading attains extremely high efficiency regardless the choice of trading methods and whether trading information is open or closed. That is, by eliminating the real nature of investment and focusing on trading, we observed high efficiency. Reversible investment experiments were carried out to compare the results with irreversible investment.

### (2) Experiment 2

We conducted 12 sessions using 72 subjects in 1999. When we introduce reversibility of investment, we found two patterns of price dynamics in emissions trading.

The first is the "failure pattern." Emissions permits are traded with relatively high price around the beginning of a session. For this reason, several countries consider that reduction investment is profitable, and hence they conduct investment actively. This causes over-investment worldwide, and hence results in excess supply of emissions permits. Nonetheless, transaction prices do not go down due to the relatively high price at the beginning and subsequent inertia. Therefore, the price of permits slumps at the end of the period. The economic efficiency of this pattern is quite low.

The second pattern is the "success pattern." Due to low prices of emissions permits around the beginning of the session, each country is hesitant about conducting reduction

investment. This causes excess demand for emissions permits and hence pressure for price rises prevails. This results in a price increase, although due to price inertia rise is gradual. Each country begins domestic reductions based on the price increase, but reductions are not sufficient to attain the Kyoto target. Therefore, the countries that require emissions permits conduct excessive reductions around the end of the period in order to avoid non-compliance penalty. The economic efficiency of this pattern is relatively high.

We use two types of trading methods in Experiment 2: bilateral trading and auction. In terms of efficiency, auction is not necessarily better than bilateral trading. Six out of seven success patterns occur in bilateral trading sessions. In auctions, every subject can access trading information instantaneously since all information is revealed to subjects. As a result, subjects can respond to the changes very quickly. On the other hand, in bilateral trading, subjects must communicate with each other in pairs and hence it takes a considerable amount of time. It seems that this “friction” of the trading method makes the system stable. Experiment 2 also uses two types of information control: informational disclosure and closure. This control does not influence the results of the experiment.

There are other experiments that are very similar to Experiment 2 conducted by International Energy Agency (IEA), Unipede, and others. The price dynamics in these experiments falls into our “failure case.” Subjects in the experiments faced pressure to comply with the Kyoto Protocol and therefore over-responded through excess investment.

### **(3) Experiment 3**

We conducted 18 sessions using 90 subjects in 2001. Our focus is liability of emissions permits, in addition to trading methods and information disclosure based upon experiment 2. Since the number of sessions is too small to conduct statistical analysis, the following findings are tentative.

There are two types of liability in emissions trading among countries: liability of trading among countries and liability to the Kyoto Protocol. Regardless of the status of reduction in a seller country, the seller must provide emissions permits based on the contract; this is called “seller’s liability”. Experiments 1 and 2 implicitly assume this liability rule.

On the other hand, depending on the status of seller countries a buyer country might not be able to receive all the contracted emissions permits; this is called “buyer’s liability.” No detailed analysis has been conducted on buyer’s liability. In our experiment, we designed two types of buyer’s liability system depending on the different priority of liability. The “country-first” liability system is where trading liability among countries has priority and the “Kyoto-first” liability system is where the promise to the Kyoto Protocol has priority.

In addition to liability rules, an important design issue is the “default” system, when a country cannot achieve its trading obligations to other countries. The order of defaulting countries and possible chain reaction of default among the countries can influence the final results of balance sheets. We designed a default system that is independent of the order in which countries default and also independent of any chain reaction. The other design feature is the penalty system when a country cannot attain the target of the Kyoto Protocol.

Consider the case where a seller country is not penalized when she cannot deliver emissions permits to buyer countries and at the same time the Protocol imposes a monetary penalty when a country cannot attain the target. Under the “Kyoto-first” liability system, in order to avoid a penalty a country must keep sufficient emissions permits to achieve the target of the Kyoto Protocol. However, once she keeps enough permits to achieve the target, she does not care about delivering emission permits to other countries as promised. That is, under this liability system the country might intentionally cause default since she does not have to deliver permits as promised.

On the other hand, under the “country-first” system, in order to avoid penalty a country must submit permits to the Kyoto regime *after* clearing the transactions among countries. Therefore, the probability of default under “country-first” liability would be smaller than that under “Kyoto-first” liability.

The Marrakesh Accords employed seller liability in the Kyoto Protocol. However, even under the seller liability system it would be inevitable to use futures transactions. In this sense, Experiment 3 is intended to reflect the post-Kyoto regime as well as the Kyoto regime.

Our experimental controls in experiment 3 are

- (a) liability system (seller, country-first, and Kyoto-first)
- (b) trading methods (auction, and bilateral); and
- (c) contract information (disclosure, and closure).

Under this design, we have 12 (=3x2x2) institutions that should be considered. But since the information under auction is revealed to every subject, we cannot conduct sessions with auction and information closure. Therefore, we have 9 different institutions. So far, we have conducted two sessions for each institution.

Figure A shows one session. The horizontal axis represents time, and twenty minutes are regarded as one year. The vertical axis represents price. At the beginning of each year, ten subjects predict the average price for this year, and then conduct reduction investment. The diamonds in Figure A show the price prediction of each subject and the average price prediction of all subjects is represented by the line graph. After the decision of reduction investment, we can determine a theoretical price level that equates the quantity demanded and supplied. Notice that this theoretical price level cannot be observed in real data in emissions trading. On the other hand, the experimenter can observe these price dynamics through demand and supply curves. Squares in Figure A show actual transactions in the session. Due to inefficient reduction investment, the transaction prices around the beginning of the session are not high enough although the theoretical price gradually increases. The transaction prices toward the end show a yo-yo effect, but this does not reflect actual supply and demand. We name the area between two lines, the price prediction line and the theoretical price line the *degree of bubble*. When the price prediction line is below the theoretical price line, we assign a negative value to the area. If the area is

positive and large, actual transaction prices are much greater than the theoretical price that equates supply and demand.

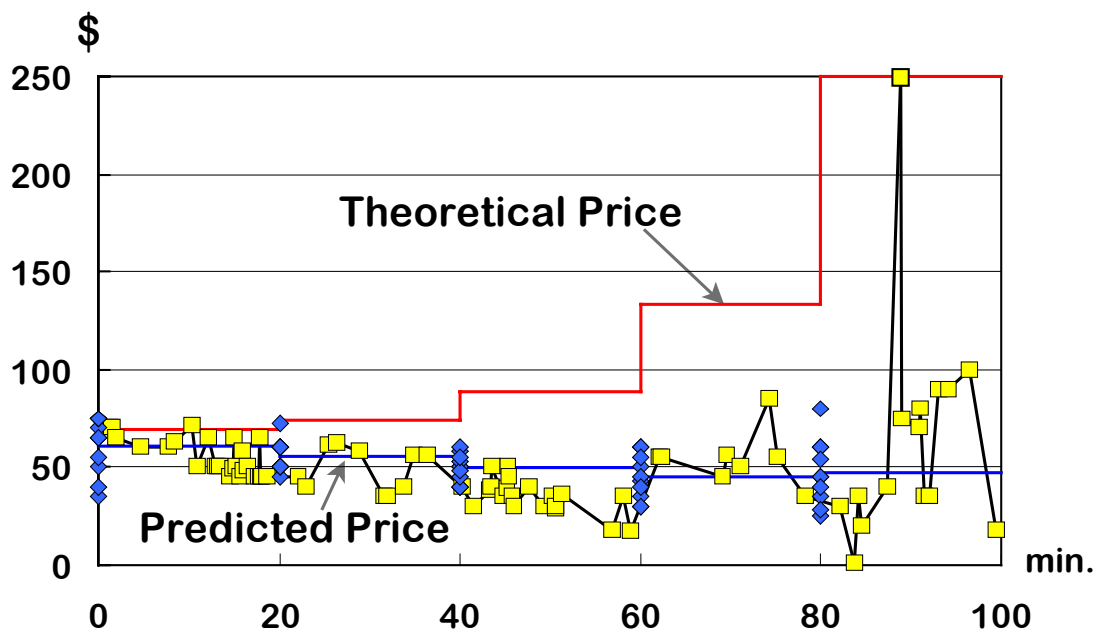


Figure A. An Example of a Session

Figure B shows the groupings of all 18 sessions. The horizontal axis shows efficiency and the vertical axis show the discrepancy area. If we examine the seller liability sessions (represented by circles), these six sessions are classified as the “failure” and the “success” patterns that were found in experiment 2. Looking at the country-first liability sessions (represented by triangles) we find a new pattern (“theoretical price increase”). This is the reverse case of the failure pattern. Here, due to low transaction prices and insufficient reduction investment, the theoretical price goes up toward the end of the session. Figure A shows this case. Finally, looking at the Kyoto-first liability sessions (represented by squares) a second new pattern (“intentional bankruptcy case”) is identified. In this case, many subjects sold emissions permits in large quantities without fully conducting reduction investment, and hence they intentionally cause default. In terms of the effect of transaction methods and information disclosure, we cannot obtain clear-cut results.

The results of experiment 1 and experiment 2 were reported in COP4 at Buenos Aires in 1998 and SBSTA10 at Bonn in 1999, and COP6 at Den Hague in 2000. Tentative results of experiment 3 were reported in COP7 at Marrakesh in 2001.

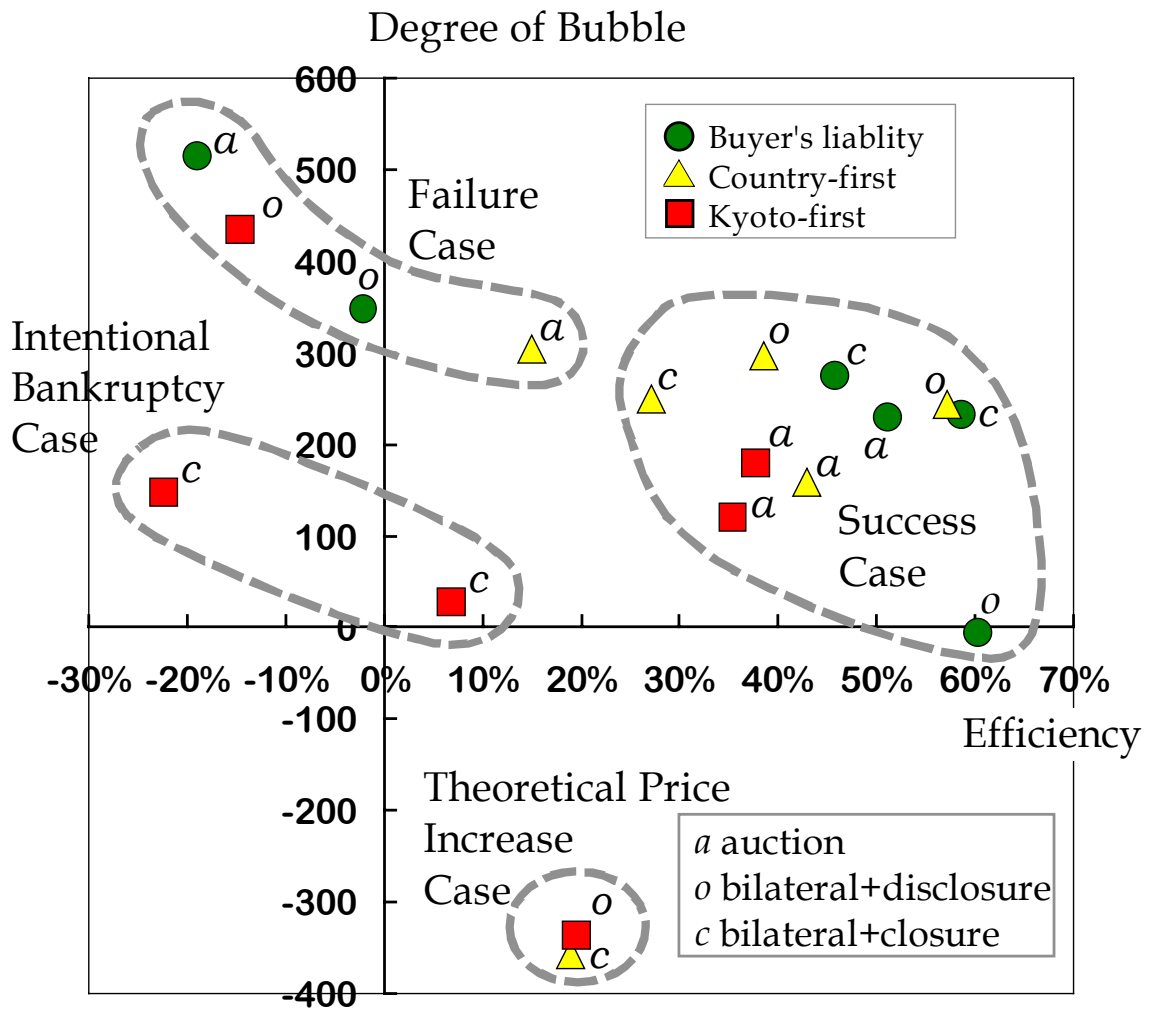


Figure B. Four Cases in Experiment 3

## 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<sup>1</sup> 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. At the COP7 held in Marrakesh in November 2001 the parties reviewed the details of the Kyoto Protocol in preparation for its ratification and adopted the Marrakesh Accords.<sup>2</sup> Following these developments, detailed design of the mechanisms from an economics viewpoint is important to further progress in this area.

Our focus in this paper is on emissions trading. Bohm (1997), an initiator of GHG emissions trading experiments, reported a bilateral trading experiment among four Nordic countries using experienced public officials or experts appointed by the Energy Ministries. The resulting prices were very close to the competitive equilibrium price, with an efficiency of allocation of 97%, which was extremely high. Muller and Mestelman (1998) and Godby, Mestelman and Muller (1998) provided many new findings on general emissions trading experiments. Among others, they found that: (i) allowing the banking of permits over time smoothes contract prices across time periods, and (ii) a trader with market power outside of the emissions trading market can influence the emissions trading market, and hence the introduction of the emissions market reduces the efficiency of the economy as a whole.<sup>3</sup>

Following these experiments, Hizen and Saijo (2001, 2002) designed an experiment, which we call *Experiment 1* in this paper, with three controls: (i) trading method, (bilateral trading or double auction), (ii) disclosure of contract information (i.e., price, quantity, identity of buyer and seller), and (iii) disclosure of marginal abatement cost curves. By changing these controls, they explored what type of institutions can efficiently attain the targets of the Kyoto Protocol related to GHG emissions reduction. The main

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<sup>1</sup> See <http://www.unfccc.de/index.html>

<sup>2</sup> President Bush announced that the USA would not ratify the Kyoto Protocol in March 2001.

<sup>3</sup> The experiments by Bohm and Carlén (1999) show that the market power problem is not as serious as Muller and Mestelman (1998) and Godby, Mestelman and Muller (1998) suggest since participants in an emissions trading market can buy *and* sell the permits.

result in Hizen and Saijo is that the efficiency of both bilateral trading and double auction is quite high, regardless of the control of contract information.<sup>4</sup>

Using almost the same experimental design, Hizen, Kusakawa, Niizawa and Saijo (2001) focused on three features that were not analyzed in Hizen and Saijo: the effects of non-compliance penalty, abatement irreversibility and the time lag effect of investment. We call this *Experiment 2* in this paper. Hizen, Kusakawa, Niizawa and Saijo obtained four main results.

First, the trading sessions can be grouped into two according to price dynamics of *point equilibrium*, an equilibrium concept first introduced in the paper. If abatement investment is irreversible, the normative equilibrium price at each point of time depends on the previous decisions of abatement investment, since abatement investment changes the shape of the marginal abatement cost (MAC) curve and hence the supply and demand curve. For example, assuming that at a certain point of time a party conducts emissions reductions greater than its competitive equilibrium reduction after other parties have already conducted their competitive equilibrium reductions exactly, the total amount of reductions would then exceed the total amount of the competitive equilibrium reductions, and hence the competitive equilibrium price at *this point of time* should be less than the competitive equilibrium price *before* conducting the session. There are therefore two sequences of price dynamics. One is actual contract price data and the other is "should be" price data derived from the actual abatement investment data. This "should be" price at each point of time is named the point equilibrium price.

In sessions that belonged to one of the two groups, which we call the "bubble case," the point equilibrium price dropped at an early stage of the transactions<sup>5</sup>: relatively high contract prices and/or fear of non-compliance caused some subjects to conduct excessive domestic reductions at an early stage, which produced an excess supply of emissions permits, and hence the point equilibrium price went down. The efficiencies of these sessions were relatively low.

In sessions which belonged to the other group, which we call the "success" case, the point equilibrium price did not drop at an early stage of the transactions: relatively low contract prices at an early stage caused insufficient domestic reduction and the point

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<sup>4</sup> The efficiencies of emissions trading were high - between 91.9% and 99.9% for bilateral trading and between 99.4% and 99.7% for double auction.

<sup>5</sup> Baron (2000) observed the same effect, although since he conducted just one session only, it is hard to generalize from the result. However the price pattern of the sulfur dioxide market in the U.S.A. showed the same price dynamics in the first few years.



equilibrium prices in the first half of the period were very close to the competitive equilibrium price. The efficiencies of these sessions were relatively high, but substantially lower than those of Hizen and Saijo.

Second, although a difference of efficiencies between double auction and bilateral trading was not observed when sessions were compared as a whole, in each group of sessions the efficiencies of double auction were higher than those of bilateral trading. That is, while an analysis of the type of transaction method alone did not give a clear-cut distinction on efficiency, analysis within each of the two groups did. On the other hand, no clear distinction on efficiency was observed between bilateral trading and double auction in Hizen and Saijo.

Third, compared with bilateral trading, double auction was more likely to result in the low efficiency group and less likely to result in the high efficiency group. That is, although double auction was likely to attain high efficiency in each group, it often resulted in low efficiency group.

Fourth, although overall efficiencies of sessions were not very high, on average emissions trading reduces the total costs of achieving the Kyoto targets compared with the carrying out of domestic reductions only.

Based upon the results of Experiments 1 and 2, we designed a new experiment, which we call *Experiment 3* in our paper, focusing on liability of emissions permits. Since there were not enough sessions to conduct a statistical analysis, our findings from this experiment are tentative.

There are two types of liability in emissions trading among countries: liability of trading among the countries and liability to the Kyoto Protocol. Regardless of the status of reduction in a seller country, the seller must provide emissions permits based on the contract; this is called the “seller’s liability” system. Experiments 1 and 2 implicitly assume this liability rule.

On the other hand, depending on the status of seller countries, a buyer country might not be able to receive all emissions permits based upon the contract; this is called “buyer’s liability” system. No detailed analysis has been conducted on buyer’s liability system so far. In our experiment, we designed two types of buyer’s liability systems, based on the order of liability. Under the “country-first” liability system, trading liability among countries is given priority, and under the “Kyoto-first” liability system the commitment to the Kyoto Protocol has priority.

In addition to the liability rules, an important design feature is the “default” system, when a country cannot achieve its trading commitments to other countries. That is, the order of defaulting countries and a possible chain reaction among countries can influence the final results of balance sheets. We designed a default system that is independent of the order of default and of any chain reaction.

The other design feature is the penalty system, applied when a country cannot attain the target of the Kyoto Protocol. Consider the case where a seller country is not penalized when she cannot deliver emissions permits to buyer countries, but at the same time the Protocol imposes a monetary penalty when a country cannot attain the target. Under the “Kyoto-first” liability system, in order to avoid any penalty, a country must keep sufficient emissions permits to achieve the target of the Kyoto Protocol. However, once she keeps enough permits to achieve the target, she does not care about the trading of emission permits among countries. That is, under this liability system a country might intentionally cause default since she does not have to deliver permits as promised.

On the other hand, under the “country-first” system, in order to avoid penalty a country must submit permits to the Kyoto regime *after* clearing the transactions among countries. Therefore, the probability of default under “country-first” liability would be smaller than that under “Kyoto-first” liability.

The Marrakesh Accords employed seller's liability in the Kyoto Protocol. However, even under the seller's liability system it would be inevitable to use futures transactions soon. In this sense, Experiment 3 is intended to reflect the design of a post-Kyoto regime as well as the Kyoto regime.

Our experimental controls in Experiment 3 are

- (a) liability system (seller, country-first, and Kyoto-first)
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- (c) contract information (disclosure and closure).

Under this design, we have 12 (=3x2x2) institutions that should be considered. But since the information under auction is revealed to every subject, we cannot conduct sessions with auction and information closure. Therefore, we have 9 different institutions. So far, we have conducted two sessions for each institution. The following are our tentative results.

First, we observed two new cases. Under the regime of seller's liability in Experiment 3, we found two cases that are exactly the same as in Experiment 2. Under country-first, however, we found a new case called the "anti-bubble" case where several subjects expected lower prices than the competitive price, and hence did not conduct enough reduction investment. This made the point equilibrium price much higher than the competitive price. Although there was some pressure for a price increase, actual contract prices remained low due to price inertia. Toward the end of these sessions, the point equilibrium price rose to the level of penalty for non-compliance. The other new case occurred under Kyoto-first liability. Although several subjects noticed that over-selling of their bonds was profitable under this regime and as a result started selling bonds excessively, it was hard to determine who was over-selling under a closed information system. Therefore some subjects who wished to obtain permits conducted excessive domestic reduction, which drove the point equilibrium price lower. At the same time, leakage of information through transactions made the bond prices of over-sellers close to zero. This case is called the "intentional bankruptcy" case.

Second, although we might think that Kyoto-first is superior to country-first since the responsibility to Kyoto should be given first priority, in our experiment the country-first buyer's liability attains higher efficiency than the Kyoto-first buyer's liability.

Third, it is not clear which is better between seller's liability and country-first liability. No significant difference on efficiency was observed between these two systems, although the variance of efficiency of seller's liability is larger than that of country-first liability.

Fourth, although the efficiency of the bubble case is quite low, the amount of over-compliance is quite high. That is, if one thinks that environmental integrity is the first priority, the bubble case may not be viewed as bad as from the viewpoint of efficiency.

This paper is organized as follows. In Section 2, the experimental design and procedures in Experiments 1 and 2 are described. The point equilibrium is explained in Section 3. Section 4 shows two types of efficiency. In Section 5, we compare the results in Experiments 1 and 2 using the point equilibrium. Section 6 describes the experimental design and procedures in Experiment 3. In Section 7 we discuss intentional bankruptcy under buyer's liabilities, and Section 8 shows the results. The final section contains concluding remarks.

## 2. Experimental Design and Procedures in Experiments 1 and 2

To explore what type of institutions can efficiently attain the targets of the Kyoto Protocol related to GHG emissions reduction, Hizen and Saijo (2001, 2002) designed an experiment with three controls: (i) trading method (bilateral trading or double auction), (ii) disclosure of contract information (i.e., price, quantity, and buyer and seller identity), and (iii) disclosure of marginal abatement cost (MAC) curves. We call this experiment *Experiment 1* in our paper.

Based on the results of Hizen and Saijo, Hizen, Kusakawa, Niizawa and Saijo (2001) employed two controls: (i) trading method and (ii) disclosure of contract information. . We call this experiment *Experiment 2* in our paper. MAC curves disclosure sessions were not conducted because almost no effect of the disclosure of MAC curves was observed in Experiment 1.

The main features of the experimental design in Experiment 1 are reversible investment, no time lag investment, and the impossibility of non-compliance. The opposite features were used in Experiment 2: irreversible investment, time lag investment, and the possibility of non-compliance.

Reversible investment is explained in Figures 1-1 and 1-2, where the horizontal axis represents the amount of emissions and the vertical axis represents MAC. The downward sloping curve is a MAC curve. Point *a* corresponds to the initial position of the subject. If the subject decides to invest in emission reductions and moves from *a* to *b* on the MAC curve, the shaded area is the abatement cost of moving from *a* to *b* and her position moves from the initial position to the new position given in Figure 1-2. The MAC curve is considered as representing marginal *cost* when a subject reduces one unit of emissions, but it can be regarded as representing marginal *benefit* when it increases one unit of emissions. If abatement investment is *reversible*, the benefit of one additional unit of emissions after the abatement investment is the height of point *b*. That is, the abatement investment is fully recoverable by increasing the emissions. This rule was applied in Experiment 1. On the other hand, if the investment is totally unrecoverable, the benefit of emitting one additional unit would be zero. Experiment 2 took the middle point between these two extremes: after any amount of emission reduction investment, the benefit of emitting one additional unit is always the height of the initial position. Further benefit of emissions decreases along the right-hand side of point *a* of the MAC curve in Figure 1-1. Therefore, the new MAC curve after moving to the new position becomes the curve depicted in Figure 1-2. That is, with

irreversible investment the shape of the MAC curve changes after abatement investment. In the case of abatement reversibility, it does not change.

In Experiment 1, there was no time lag between investment and emissions reduction: subjects could reduce their emissions immediately after deciding to do so, even just before the end of the commitment period. In Experiment 2, on the other hand, subjects could not reduce their emissions if they decided to do so just before the end of the period, since actual abatement took a considerable time due to the investment time lag.

An important issue in the negotiation process of the design of the Kyoto Protocol has been what type of penalty would be appropriate when a party cannot comply with the Kyoto target (non-compliance).<sup>6</sup> In focusing on type of trading institutions, Experiment 1 was designed so that non-compliance and over-compliance would not occur in order to exclude their effect: each subject started the experiment having achieved the goal required by the Kyoto Protocol, and when they sold (bought) permits, they were required to reduce (increase) emissions by the same amount. Thus in Figure 1-1 the subjects could reduce their emissions from  $a$  to  $b$  only when they could sell the same amount of permits to another subject. In Experiment 2, non-compliance and over-compliance could occur: each subject started the experiment without achieving their goal, and could sell or buy their permits even if they did not reduce or increase their emissions. Two rules concerning non-compliance and over-compliance were adopted: (i) when a party ended with non-compliance, a penalty approximately two and a half times higher than the competitive equilibrium price per unit was imposed, and (ii) when a party ended with over-compliance, any remaining permits had no value.

In both experiments a minimum of six students were recruited for each session through campus-wide advertisements at Osaka University. The students were told that there would be an opportunity to earn money in a research experiment (in the recruitment, no term was used peculiar to emissions trading). The sessions were conducted two or three days after recruitment. In each session, subjects were seated at desks in a relatively large room and listened to a tape-recorded voice giving instructions. During this part, each subject received a sample MAC curve.

Figure 2-1 is a sample graph used in Experiment 1. The upper half is a sample MAC curve. The horizontal axis represents the amount of an abstract commodity and the

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<sup>6</sup> Japan insists that the individual targets are only objectives and hence no penalty should be imposed for non-compliance. However, most parties, including the US, the EU and developing countries, advocate strong penalties, including monetary punishment.

vertical axis represents the marginal cost. Each subject was told that the initial position is at 0.<sup>7</sup> When they bought (sold) the commodity, they moved to the right (left) on the curve and earned benefits (obtained a profit), equivalent to buying (selling) permits and conducting additional emissions (emissions reductions). All possible situations in Experiment 1 are depicted in the lower half of Figure 2-1.

Figure 2-2 is a sample graph used in Experiment 2. Because the direction of horizontal axis in the figure is opposite to that in Figure 2-1, the MAC curve is upward sloping. Each subject was told that they would start from "your initial holding" (20 units in the sample figure), which was also called "your initial position," and that they should finish with a number of units more than or equal to the goal (70 units in the sample figure). The initial position represents initial emissions and "your goal" the target of the Kyoto Protocol. When subjects move one unit to the right (left) along the curve from the initial position, they obtain (lose) one unit of goods in exchange for paying (receiving) 100 units of money, equivalent to a reduction (increase) of one unit of emission from their initial emissions. In the experiment, one unit of emissions reduction was termed "producing the unit", and one unit of increment of emissions was termed "returning the unit to the experimenter." Figure 3 shows possible situations in Experiment 2. In this figure the Kyoto target is on the right-hand side of the initial position. Assuming that the price level of permits is at  $p$ , for maximum gain the subject should reduce their emissions until MAC is equalized to the price, that is, from  $a$  to  $b$ , and should then sell the difference between the Kyoto target and the new position, that is, from  $b$  to  $c$ . Additional cases where the price level was at  $p'$  and where the target was on the left-hand side of the initial position were also shown to subjects.

After instruction, all subjects took an examination to check their understanding of the instruction. The top six subjects continued the session, and the rest of the subjects were asked to leave the room with \$13.16 (\$1=114 yen). The six subjects were assigned a subject number between 1 and 6 (equivalent to the roles of Russia, Ukraine, USA, Poland, EU, and Japan) and received their own MAC curves (in the MAC curves disclosure sessions in Experiment 1 they also received MAC curves of the other subjects). Figure 4 shows the MAC curve of each subject. In this figure their MAC curves are shifted so that their Kyoto targets come to the origin, or 0. An MAC curve can be regarded as an excess demand curve

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<sup>7</sup> Hizen and Saijo implicitly presume that position 0 is the position where each country attains the goal required by the Kyoto Protocol. The experimental setting asks what kind of trading method should be adopted in order to achieve that goal and does not address the non-compliance issue.

for emissions permits when we consider the Kyoto target the new origin: on its left-hand side, the MAC curve becomes the supply curve of the permits, and on its right-hand side, the MAC curve becomes the demand curve. The initial position for each subject in Experiment 1 is the origin, and the initial position in Experiment 2 is the solid circle on the curve. Subjects were given fifteen minutes to strategize before the sixty-minute trading period started.<sup>8</sup>

In bilateral trading each subject could move around the room freely to find a subject with whom to transact. To avoid information leakage, subjects were not allowed to talk during negotiations; only numbers (price and quantity) and "yes" and "no" symbols were exchanged on their negotiation sheets. Once a pair reached agreement, they reported the price, quantity, and their subject numbers to an experimenter. In bilateral trading with open contract information sessions, the experimenter announced this information and wrote it on a blackboard.

In double auction, an auctioneer called on the subject who raised their hand the earliest. The subject then provided her subject number, sell or buy decision, quantity, and price per unit (for example "Subject five wants to sell ten units at one hundred dollars per unit"). The auctioneer projected the proposal onto a screen using an OHP sheet and the subject who raised their hand the earliest could either accept the proposal or make another proposal. The accepted quantity had to be smaller than or equal to the proposed quantity. On proposals, the "improvement rule" was imposed, that is, asks (bids) had to be successively lower (higher).<sup>9</sup>

Only in Experiment 2, in order to reduce or increase emissions, a subject informed the experimenter of the amount of emissions reduction or additional emissions; this information was not known to the other subjects. These reductions or increases could be carried out only in the first half of the sixty-minute trading period. After half an hour the point on the MAC curve is fixed for the rest of the period. If a subject ended the experiment with non-compliance, they paid a penalty of 300 per over-emissions unit; if a subject ended with over-compliance, any remaining permits had no value.

In Experiment 1, it took approximately 160 minutes for each session with a mean payoff per subject of \$31.52 (maximum payoff was \$66.67, minimum payoff was \$17.54). In Experiment 2, it took approximately three hours for each session with a mean payoff per subject of \$34.61 (maximum payoff was \$66.34, minimum payoff was \$17.54).

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<sup>8</sup> Each session had just one period.

### 3. Point Equilibrium

In Experiment 2, due to changes of the shapes of MAC curves caused by abatement investment irreversibility described in Section 2, the normative competitive equilibrium price also changes, as illustrated by Figure 5. This figure is similar to Figure 1 but the position of the Kyoto target is explicitly expressed, so that the downward sloping curve is regarded as a demand curve for emissions permits and the supply curve (the upward sloping curve in the figure) is derived from the MAC curves of other parties. Before any abatement investment, the competitive equilibrium is  $e$  and the competitive equilibrium price is  $p^*$ . If a demander conducts excessive abatement investment and moves from point  $a$  to point  $b$  however, the normative competitive equilibrium *after* this investment would no longer be at  $e$ , but at  $e'$  and the new competitive equilibrium price becomes  $p'$ . At each point of time, therefore, the normative competitive equilibrium can change as abatement investments proceed. The normative competitive equilibrium given previous actions of subjects at a certain time is called the *point equilibrium* at the time.

In Experiment 1, the competitive equilibrium price and the point equilibrium price always coincide throughout the period because abatement investment is reversible and the shapes of MAC curves cannot be changed. In Experiment 2, on the other hand, although they coincide at the starting point they do not always coincide throughout the period because the shapes of MAC curves can change as time proceeds. There are therefore three price sequences in a session: the first is the sequence of real contract price data; the second is the normative competitive equilibrium price sequence which is constant throughout the period; the third is the point equilibrium price sequence. While the first two sequences are usually compared in experimental economics literature, it is shown in Section 5 that the analysis of price dynamics is enriched by the introduction of the point equilibrium price sequence.

### 4. Two Definitions of Efficiency

In the experiments, efficiency is defined as follows:

$$\frac{\text{The sum of surplus extracted in the experiment}}{\text{The sum of surplus extracted at competitive equilibrium}}$$

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<sup>9</sup> See Davis and Holt (1993: p. 41).



This is a standard measure of efficiency, which is usually measured as the percentage of the realized sum of surplus to the maximum possible sum of surplus which is attained at the competitive equilibrium. In Experiment 1, where non-compliance and over-compliance are not possible, this value is uniquely measured. In Experiment 2, on the other hand, two types of efficiency measures are employed, depending on how "the sum of surplus extracted in the experiment" is measured when non-compliance and/or over-compliance occur. The first method is to measure "the sum" as the sum of the actual payoffs obtained during the experiment. For example, when a subject ended with over-compliance, the cost of her unnecessary abatement was subtracted from her payoff and hence from "the sum". On the other hand, when a subject ended with non-compliance, a penalty was subtracted from her payoff and hence from "the sum".

There are two problems with this measure of efficiency. Firstly, the permits left over under over-compliance will have some value since the Kyoto protocol allows the banking of permits and over-compliance represents a reduction of GHGs beyond the targets of the Kyoto protocol, which means it would be natural to assign value to the leftover permits. Secondly, penalties from non-compliance would be handed to an international body and would be distributed to other parties, so that the total sum of the penalties would not be a source of loss of efficiency.

Given these two problems, efficiency in Experiment 2 is modified in the following manner. When some subjects are under over-compliance and nobody is under non-compliance, one unit of over-compliance is re-evaluated using the value of the subject who has the highest marginal emission benefit. Hypothetically, therefore, the subject obtains benefit by using one unit of over-compliance. The same re-evaluation is then carried out for the next unit of over-compliance using the value of the subject who has the second highest marginal emission benefit. The process is then applied to subsequent units until the last unit of over-compliance is re-evaluated. Since the shape of the marginal abatement cost curve (or the marginal emission benefit curve) of each subject will have been changed at the end of a session due to abatement irreversibility, re-evaluation is carried out using this reshaped marginal emission benefit curve.

When some subjects are under non-compliance and nobody is under over-compliance, one unit of non-compliance penalty is replaced with the marginal abatement cost of the subject who has the lowest marginal abatement cost. Hypothetically, the subject

reduces one unit of emission instead of another subject's paying one unit of penalty. The same replacement is then carried out for penalty for the next unit of non-compliance using the second lowest marginal abatement cost and the same process is then applied to subsequent units until penalty for the last unit of non-compliance is replaced.<sup>10</sup>

Figure 6 shows an example where at the end of a session subject A is under over-compliance and subject B complies with the target exactly. Both marginal abatement cost curves have kinks at the end positions of the session due to abatement irreversibility. The amount of over-compliance for subject A is  $0-m$ , and the end position of subject B is exactly at the Kyoto target. The subject who has the highest marginal emission benefit is subject B. That is, the height of  $i$  is greater than the height of  $k$ . Hence, the benefit from emitting from  $i$  to  $n$  is the area  $0-q-n-i$ . At  $n$ , the marginal benefit of subject B becomes exactly the same as that of subject A at  $k$ . From this point, the benefit can be obtained from both subjects A and B, and is the area  $q-m-k-j-n$ . In total, the over-compliance of  $0-m$  generates the benefit depicted by the area  $0-m-k-j-i$ .

The re-evaluation of over-compliance in Figure 6 can be interpreted as a hypothetical trade after the end of the session. Immediately after the session subject A emits the amount  $m-l$  and hence obtains the benefit  $l-m-k-j$ . Subject A then sells the amount  $0-l$  to subject B at the point equilibrium price  $p$  and obtains the benefit  $0-l-j-p$ . On the other hand, subject B pays subject A  $0-l-j-p$  and obtains the benefit  $0-l-j-i$  by emitting the amount  $0-l$ , for a net benefit of  $p-j-i$ . In total, the sum of the surplus is equivalent to the area  $0-m-k-j-i$ .

## 5. Results in Experiments 1 and 2

### 5.1 Analyses with Efficiency Table

In this section we analyze experimental results using Efficiency Tables 1, 2 and 3, which provide a summary of the sessions.

The bilateral trading in Experiment 1 has two controls: (i) disclosure or closure of contracted prices, and (ii) disclosure or closure of marginal abatement cost curves. Therefore, there are four treatments. Repeating the same treatment twice yields eight sessions. In what follows, "O" represents "disclosure" and "X" represents "closure". For example, "OX2" indicates session 2 in the price disclosure, marginal abatement cost curve closure treatment.

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<sup>10</sup> In Experiment 2, there were no sessions where both a subject with over-compliance and a subject with non-compliance co-existed.

In this experiment, the competitive equilibrium price ranges from 118 to 120 so that 119, the midpoint between 118 and 120, is regarded as the competitive equilibrium price. At this price, the total amount of benefit and profit (that is, the maximum amount that these six subjects can enjoy) is 6990. In Table 1 the top row indicates the name of the sessions, the left column shows the I.D. numbers of subjects, and the numbers in parentheses are their benefits or profits at the competitive equilibrium price. In each cell, the upper figure is the actual benefit or profit that the subject earned and the lower figure is the efficiency of this subject. For example, the 0.732 figure for subject 1 in session "OO2" is the ratio between 1870 and 2555, which is termed individual efficiency.

Subject No.	OO1	OO2	OX1	OX2	XO1	XO2	XX1	XX2
1(2555) (Russia)	1420 0.556	1870 0.732	960 0.376	1710 0.669	1510 0.591	1100 0.431	1460 0.571	1600 0.626
2(1290) (Ukraine)	1140 0.884	914 0.709	360 0.279	1665 1.291	1320 1.023	940 0.729	1536 1.191	2370 1.837
3(610) (U.S.A.)	685 1.123	683 1.120	2060 3.377	372 0.610	1846 3.026	615 1.008	583 0.956	550 0.902
4(390) (Poland)	520 1.333	570 1.462	850 2.179	530 1.359	500 1.282	555 1.423	910 2.333	500 1.282
5(620) (EU)	800 1.290	1105 1.782	1300 2.097	755 1.218	-150 -0.242	1080 1.742	81 0.131	150 0.242
6(1525) (Japan)	2425 1.590	1800 1.180	1450 0.951	1844 1.209	1400 0.918	2700 1.770	2390 1.567	1800 1.180
Sum(6990)	6990 1	6942 0.993	6980 0.999	6876 0.984	6426 0.919	6990 1	6960 0.996	6970 0.997

Table 1. Efficiency of Bilateral Trading in Experiment 1

As Table 1 shows, with the exception of "XO1", the efficiency of each session is quite high. The reason for the low efficiency level in session "XO1" is that subject 5 traded with other subjects despite suffering a loss.

**Result 1.** *When investment is reversible and does not have a time lag, the efficiency of bilateral trading is statistically larger than zero, and is almost one.*

In a double auction, all proposals, including contract prices and quantities, are disclosed. Therefore, the double auction in Experiment 1 has only one control: disclosure or closure of marginal abatement cost curves. There were five sessions in total, three disclosure sessions and two closure sessions. In Table 2, these sessions are denoted by "O3," "X2" and so on.

Subject No.	O1	O2	O3	X1	X2
1 (2555) (Russia)	2410 0.943	2410 0.943	1981 0.775	2260 0.885	2865 1.121
2 (1290) (Ukraine)	1320 1.023	1320 1.023	520 0.403	1770 1.372	1120 0.868
3 (610) (U.S.A.)	850 1.393	865 1.418	1144 1.875	681 1.116	1270 2.082
4 (390) (Poland)	200 0.513	350 0.897	230 0.590	209 0.536	355 0.910
5 (620) (EU)	750 1.210	500 0.806	1380 2.226	700 1.129	0 0.000
6 (1525) (Japan)	1430 0.938	1515 0.993	1695 1.111	1350 0.885	1360 0.892
Sum (6990)	6960 0.996	6960 0.996	6950 0.994	6970 0.997	6970 0.997

Table 2. Efficiency of Double Auction in Experiment 1

As Table 2 shows, the efficiency of each session is quite high.

**Result 2.** *When investment is reversible and does not have a time lag, the efficiency of double auction is statistically larger than zero, and is almost one.*

In Experiment 2, there are two experimental controls: the trading method and the disclosure of contract information. There are therefore three types of sessions: (i) bilateral trading session with contract information closed ("Bc" session), (ii) bilateral trading session with contract information open ("Bo" session), and (iii) double auction session with contract information open ("D" session). Since each type was conducted four times, there are twelve sessions in total.

Table 3 gives results from the 12 sessions. In addition to the two figures in each cell given in Table 1 and Table 2, Table 3 provides additional figures at the bottom of each cell. The number in the first parentheses at the bottom of each cell in the first column corresponds to the initial position in Figure 4. The first number in the second parentheses is the position in Figure 4 to which it should reduce its emissions at a price of 119; the second number is the amount of non-compliance. If the subject follows the transaction at the competitive equilibrium, this should be 0. For example, Russia, whose subject number is 1, can make the maximum surplus 2555 at the price 119 when she reduces her emissions from her initial position -32 to the point -55, and sells her permits until the amount of non-

compliance becomes 0. From the second column, the first number in the bottom of each cell shows the final position in Figure 4 and the second number shows the amount of non-compliance at the end of the session. In the case of over-compliance, this number is negative. In session Bc3, for example, Russia achieved a surplus of 620; the ratio of this surplus to the surplus she extracts at the competitive equilibrium is  $620/2555 = 0.243$ ; she reduced emissions to the point -65, that is, 10 units of over-reduction; the amount of non-compliance was -22, that is, 22 units of over-compliance. A bold square around the cell indicates over-compliance, a bold square with gray shading in the cell indicates non-compliance. The bottom four rows of the table show the sum of the surplus each subject extracted and the efficiency of the session both before and after the modification of efficiency described in section 4. In session Bc1, for example, the sum of the surplus is 5112 and the efficiency is  $5112/6990 = 0.731$ . The surplus after modification is 5612 and the modified efficiency is  $5612/6990 = 0.803$ .

	Bilateral Trading								Double Auction			
Session No.	Bc1	Bc2	Bc3	Bc4	Bo1	Bo2	Bo3	Bo4	D1	D2	D3	D4
Subject No.												
1 (2555)	1535	1600	620	656	1415	384	1825	1465	1425	2435	1360	2060
(Russia)	0.601	0.626	0.243	0.257	0.554	0.150	0.714	0.573	0.558	0.953	0.532	0.806
(-32)(-55,0)	-40, 0	-32, 0	-65, -22	-42, 0	-55, -3	-52, 0	-33, 0	-52, 0	-55, 0	-65, 0	-44, 0	-60, 0
2 (1290)	766	1175	1820	700	-565	2625	1285	2200	1195	-30	850	-1925
(Ukraine)	0.594	0.911	1.411	0.543	-0.438	2.035	0.996	1.705	0.926	-0.023	0.659	-1.492
(-10)(-30,0)	-28, 0	-20, 0	-30, 0	-20, 0	-20, -15	-20, 0	-25, 0	-20, 0	-30, 0	-30, -27	-20, 0	-30, -37
3 (610)	1046	220	556	1416	-4130	-4094	481	316	890	641	769	-404
(U.S.A.)	1.715	0.361	0.911	2.321	-6.770	-6.711	0.789	0.518	1.459	1.051	1.261	-0.662
(55)(50,0)	23, 0	30, 3	23, 0	23, 0	-20, -30	50, 23	23, 0	23, -2	40, 0	23, 0	23, 0	23, 0
4 (390)	240	100	20	94	77	500	300	450	165	275	375	763
(Poland)	0.615	0.256	0.051	0.241	0.197	1.282	0.769	1.154	0.423	0.705	0.962	1.956
(-5)(-10,0)	-5, 0	-10, 0	-17, 0	-10, 0	-10, 0	-10, 0	-13, 0	-10, 0	-10, 0	-10, 0	-11, 0	-17, 0
5 (620)	-650	375	850	850	1002	975	630	965	760	-900	770	682
(EU)	-1.048	0.605	1.371	1.371	1.616	1.573	1.016	1.556	1.226	-1.452	1.242	1.100
(25)(20,0)	5, -5	10, 0	25, 0	20, 0	20, 0	20, 0	20, 0	20, -2	20, 0	10, -10	20, 0	20, 0
6 (1525)	2175	2130	-3100	1710	1931	2040	1625	340	2515	25	1822	1200
(Japan)	1.426	1.397	-2.033	1.121	1.266	1.338	1.066	0.223	1.649	0.016	1.195	0.787
(40)(25,0)	35, 0	25, 0	15, -25	35, 6	35, 0	25, 0	25, 0	30, -5	35, 0	25, -10	25, -5	25, 0
Sum (6990)	5112	5600	766	5426	-270	2430	6146	5736	6950	2446	5946	2376
Efficiency	0.731	0.801	0.110	0.776	-0.039	0.348	0.879	0.821	0.994	0.350	0.851	0.340
Sum (6990)	5612	6230	4136	6686	3140	6680	6146	6596	6950	5856	6426	5186
Modified	0.803	0.891	0.592	0.957	0.449	0.956	0.879	0.944	0.994	0.838	0.919	0.742

Table 3. Efficiency in Experiment 2

Results given in Table 3 show that when investment is irreversible and has a time lag, efficiency drops considerably. However, on average the market achieves both positive efficiency and positive modified efficiency, indicating that emissions trading reduces the

total costs of the Kyoto target at the market level compared with the case where only domestic reductions occur.

**Result 3.** *When investment is irreversible and has a time lag, the efficiency and modified efficiency are statistically larger than zero.*

In Experiment 1, no differences were observed between the efficiency of bilateral trading sessions and that of double auction sessions, between the efficiency of contract information disclosure sessions and that of contract information closure sessions, and between the efficiency of MAC information disclosure sessions and that of MAC information closure sessions.

In Experiment 2 also, no difference is observed between the modified efficiencies of the two trading institutions when comparing data from all sessions. However, when the sessions are classified into two groups according to their dynamic processes (such as the path of point equilibrium price) a difference between the modified efficiency of double auction and that of bilateral trading is observed.<sup>11</sup>

## 5.2 Classification of the Sessions by their Dynamic Processes

Figure 7 (session Bc1) illustrates the dynamic processes of transactions, emissions reductions, and additional emissions as time passes. In this figure, the horizontal axis represents minutes and the vertical axis represents MAC and price. Squares in the figure show transactions. The left-hand (right-hand) side letter of a square represents the initial letter of the seller (buyer) and the number under the square the quantity traded. Lozenges (triangles) show the emissions reduction (additional emissions). The letter attached to a lozenge (triangle) represents the initial letter of the subject who conducted emissions reduction (additional emissions) and the number under the lozenge (triangle) the amount of emissions reduction (additional emissions). The gray (or green) horizontal line shows the competitive equilibrium price ranging from 118 to 120. The black (or dark red) line represents the point equilibrium price path up to 30 minutes. It has some thickness until 14 minutes, then becomes 120 until just before 30 minutes, when it drops to 85. The dotted line shows the point equilibrium price path after 30 minutes, which is zero if over-compliance occurs, 300 if non-compliance occurs, and 0-300 if complied with exactly.

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<sup>11</sup> No significant effects for price disclosure were observed even after the classification.

By comparing these figures for each session it is observed that the pattern of the point equilibrium path up to 30 minutes varies considerably from session to session: in some sessions it drops early and in others it is almost the same as the competitive equilibrium price. That is, sessions are characterized by their pattern of the point equilibrium path. As a measure of these path patterns Hizen, Kusakawa Niizawa and Saijo introduce the concept of *discrepancy area*, which is the area of the region enclosed by the midpoint of the competitive equilibrium price up to 30 minutes, i.e. 119, and the sequence of the midpoints of the point equilibrium prices up to 30 minutes. This area becomes larger based on how early the discrepancy between the competitive equilibrium price and point equilibrium prices occurs and/or how large this discrepancy is. An example is given in Figure 8, where the discrepancy area is shaded. In this session, the point equilibrium price dropped early and the degree of the drop was large, so that the discrepancy area is also large. In session Bc1 (Figure 7), however, the discrepancy between the competitive equilibrium price and the point equilibrium prices occurred just before 30 minutes, so that the discrepancy area is almost zero.

After normalizing the discrepancy area and the modified efficiency, Hizen, Kusakawa Niizawa and Saijo use cluster analysis to classify the sessions. The twelve sessions are first divided into two groups, i.e., session Bo1 and the other eleven sessions, then the eleven sessions are further divided into two groups, i.e., sessions Bc3, D2, D3 and D4, and sessions Bc1, Bc2, Bc4, Bo2, Bo3, Bo4 and D1.

Figure 7 (session Bc1) is an example from the largest group, i.e. sessions Bc1, Bc2, Bc4, Bo2, Bo3, Bo4 and D1, termed the success case. In this session, low contract prices at the early stage caused insufficient emissions reduction for suppliers such as Russia, Ukraine and Poland. Therefore, just before 30 minutes the USA and EU, who could not buy enough permits, reduced their emissions to levels where their MACs exceeded the point equilibrium price 120. These excessive reductions caused the point equilibrium price to drop to 90. This type of dynamic process also applies to the other sessions that belong to this group. That is, relatively low contract prices at the early stage caused insufficient emissions reduction of suppliers and as a result in many cases demanders conducted excessive reductions just before 30 minutes in order to avoid a non-compliance penalty. Although this caused efficiency losses, the losses were minor.

Figure 8 (session D2) is an example from the second largest group, i.e. sessions Bc3, D2, D3 and D4, termed the bubble case. In this session because of the relatively high

contract prices around the first 10 minutes, Japan and Russia conducted excessive reductions at that time. Although this caused a drop of the point equilibrium price, contract prices did not drop immediately due to inertia of contract prices. Accordingly, Ukraine and the USA continued to reduce their emissions at around 15 minutes based on the former contract prices, so that the point equilibrium price dropped even further. This type of dynamic process also applies to the other sessions that belong to this group. That is, at the early stage high contract prices and/or expectation of high contract prices in the future caused some subjects to reduce their emissions to levels where their MACs exceeded the competitive equilibrium price. Accordingly, the point equilibrium price immediately decreased, but due to inertia contract prices did not drop immediately. Therefore some subjects continued reducing their emissions to levels where their MACs exceeded the new point equilibrium price, not knowing that the point equilibrium price had decreased. These excessive reductions caused the point equilibrium price to decrease even further. This cycle caused great efficiency losses.

In the third and smallest group, session Bo1, the USA reduced her emissions at extremely high MACs at the early stage and as a result the point equilibrium price dropped heavily. However the contract prices remained at about the same level as the contract prices at the early stage because of inertia and as a result subjects continued to conduct excessive reductions. Because these dynamic processes are the same as those of the second largest group, these two groups are combined into one.

The total sessions are thus divided into two by cluster analysis using two variables, i.e., modified efficiency and discrepancy area, and by reclassification according to the dynamic processes of transactions and emissions reduction.

**Result 4.** *When investment is irreversible and has a time lag, two patterns of price dynamics are observed.*

Figure 9 shows a scatter diagram of the 12 sessions, where the horizontal axis represents modified efficiency and the vertical axis represents the discrepancy area. The number above the session name is modified efficiency and the number below is efficiency. Where the two efficiencies are the same, only the modified efficiency is included. The figure illustrates that sessions belonging to the success case are densely located around the southeast corner and sessions belonging to the bubble case are located further away from the corner. This visual impression confirms the cluster analysis described above.



By the use of the classification, the following two results were obtained in Experiment 2.

**Result 5.** *Bilateral trading is statistically more likely to result in the success case and less likely to result in the bubble case than double auction.*

**Result 6.** *In both groups, the modified efficiency of double auction is statistically higher than that of bilateral trading.*

In comparing all sessions, there was no significant difference between the modified efficiencies. This can be explained from Results 5 and 6, which show that although double auction attains higher modified efficiency than bilateral trading, the bubble case (which is likely to result in low modified efficiency) occurs more frequently in double auctions, so that the two effects offset each other.

## **6. Experimental Design and Procedures in Experiment 3**

We designed an experiment with three controls: (i) trading method (bilateral trading or double auction), (ii) disclosure of contract information (i.e., price, quantity, and buyer and seller identity), and (iii) liability rules (seller's liability, country-first buyer's liability, and Kyoto-first buyer's liability). Under this design, we have 12 (=2x2x3) institutions that should be considered. However, since the contract information under double auction is revealed to all subjects, we cannot conduct double auction sessions with contract information closed. Therefore, we have 9 different institutions. For each institution, we conducted two sessions using the same ten subjects, so that we have 18 sessions as a whole.

There are at least two types of contract between sellers and buyers in GHG emissions trading. In the first type of contract, called "seller's liability", absolutely valid emissions rights, or permits which can be used to comply with Kyoto targets, is transferred from a seller to a buyer immediately after the transaction. Permits transacted are absolutely valid irrespective of the state of seller's compliance, so that if the seller sold permits without conducting emissions reduction and ended with non-compliance, the seller has to pay penalty for non-compliance, and the buyer can use the permits she bought towards her compliance. That is, the seller has to assume liability for selling permits which are not supported by emissions reduction, thus this type of contract is termed "seller's liability."

In the second type of contract, called "buyer's liability", emissions rights are not transferred from a seller to a buyer immediately after the transaction. The commodity traded is not an absolutely valid emissions right but a bond, the validity of which towards the buyer's compliance is determined by the state of the seller after the commitment period. For example, if the seller sold a bond without conducting emissions reduction, the bond may become invalid for the buyer; that is, the buyer assumes liability for buying permits which are not supported by emissions reductions. This type of contract is called "buyer's liability."

Under buyer's liability, there are at least two types of liability rules depending on how the validity of bonds is judged, or depending on which responsibility has priority: responsibility to other countries or responsibility to the Kyoto Protocol (the compliance committee). For example, if country A sold a bond to country B, country A has responsibility for guaranteeing the validity of the bond towards country B's compliance, that is, country A has responsibility for guaranteeing that she transfers her right to emit to country B. On the other hand, each country has to retain emissions rights equal to the amount she has emitted. This is responsibility to the Kyoto Protocol. If the sum of responsibility to other countries and responsibility to the Kyoto Protocol exceeds the amount of emissions rights she holds, she cannot fulfil all of her responsibilities. In this case, the result would vary according to which of the responsibilities has to be fulfilled first. We term the liability rule where responsibility to another country has to be carried out first "country-first buyer's liability" ("country-first"), and the liability rule where responsibility to the Kyoto Protocol has to be carried out first "Kyoto-first buyer's liability" ("Kyoto-first"). In the following, the term "default" is used when a country cannot carry out her responsibility to other countries, and the term "non-compliance" is used when a country cannot fulfil responsibility to the Kyoto Protocol.

Liability rules are designed as follows. In both seller's liability and buyer's liability, country  $i$  ( $=1, \dots, N$ ) receives  $R_i$  units of absolutely valid emissions rights, or an assigned amount, from the compliance committee. In seller's liability, each country can trade these emissions rights within the commitment period, and after the commitment period has finished retires to the compliance committee as many emissions rights as she has emitted, that is, she carries out her responsibility to the Kyoto Protocol and if able to do so ends with compliance (otherwise non-compliance). Under buyer's liability, on the other hand, each country trades not emissions rights but promises, or bonds, to deliver emissions rights at the end of the commitment period. Under buyer's liability, bonds issued by different

countries are different commodities, so that the number of the types of bonds is equal to the number of countries. In the following, the bond issued by country  $i$  is called bond  $i$ , and the amount of bond  $i$  held by country  $j$  is denoted by  $B_{ij}$ .<sup>12</sup> After the commitment period, each country carries out their responsibilities to the other countries and their responsibility to the Kyoto Protocol.

Under country-first buyer's liability, we first check whether each country can carry out all of her promises. When  $R_i + \sum_j B_{ji} < \sum_i B_{ij}$ , country  $i$  cannot carry out all of her promises and she is therefore in default because even if all the other countries carry out their promises, the amount of emissions rights after the receipt,  $R_i + \sum_j B_{ji}$ , is less than the amount of promises to the other countries,  $\sum_i B_{ij}$ . Therefore, country  $i$  results in bankruptcy and her account is settled. In the settlement, country  $j$ , one of the holders of bond  $i$ , is distributed emissions rights and bonds held by country  $i$  based on the ratio of  $B_{ij}$  to  $\sum_i B_{ij}$ ; that is, country  $j$  is distributed  $R_i \left( B_{ij} / \sum_i B_{ij} \right)$  units of emissions rights and  $B_{ki} \left( B_{ij} / \sum_i B_{ij} \right)$  units of bond  $k$  ( $=1, \dots, N$ ). If, as a result of this settlement, some country results in bankruptcy, we settle her account. When more than one country results in bankruptcy, we settle their accounts based on an order. In the rules described above, the order of the settlement of the countries does not affect the final outcome.<sup>13</sup> We repeat this process until there is no bankruptcy. Following all bankruptcy settlements, bonds become equivalent to emissions rights because all promises can be carried out, so that bonds held by each country are exchanged for emissions rights held by the issuer of the bond. Settlement among countries is then finished, and each country carries out their responsibility to the Kyoto Protocol; each country has to retire as many emissions rights as she emitted, and if able to do so ends with compliance (otherwise non-compliance).

Under Kyoto-first buyer's liability, first each country has to retire to the compliance committee as many permits as she emitted. Some countries may not be able to do this, but they can still comply if they obtain emissions rights in the settlement with other countries. Second, each country carries out their responsibility to other countries, which is the same process as settlement under country-first buyer's liability. After the settlement finishes, countries who have not yet complied must retire emissions right to the compliance committee, and if able to do so ends with compliance (otherwise non-compliance).

In order to observe what may happen when the difference between penalties for the two responsibilities is very large, we set the penalty for default at 0 and penalty for

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<sup>12</sup> We define  $B_{ii} = 0$  for all  $i$ .

<sup>13</sup> See Kuga (2002).

non-compliance at 250 per unit, which is about 3.7 times larger than the competitive equilibrium price 67.<sup>14</sup>

In double auction, subjects send to the market an order where the following are specified: (i) the name of commodity, (ii) sell or buy, (iii) price, (iv) quantity, and (v) the term of validity of the order. Subjects do not need to specify the name of the commodity in the seller's liability sessions because only emissions rights are traded. In buyer's liability sessions, on the other hand, subjects need to specify the commodity from among ten types of bonds (because the number of subjects is ten). For price and quantity, subjects can specify both (sell or buy at her limit), or specify only quantity (sell or buy by the market). When an ask (bid) is 30 units at \$50 per unit, it is first matched with the highest bid (lowest ask) which is higher (lower) than \$50. Then it is matched with the second highest bid (second lowest ask) which is higher (lower) than \$50. This process ends when all 30 units of ask (bid) are matched with other bids (asks), or when no bids (asks) that are higher (lower) than \$50 is left in the market. On the other hand, when an ask (bid) is to sell (buy) 30 units by the market, it is matched with the highest bid (lowest ask), then matched with the second highest bid (second lowest ask) and so on until all 30 units of ask (bid) are matched with other bids (asks). We do not impose the "improvement rule", where asks (bids) have to be successively lower (higher).<sup>15</sup>

In bilateral trading, subjects send to other subjects negotiating card where the following are specified: (i) the name of commodity, (ii) sell or buy, (iii) price, (iv) quantity, (v) the term of validity of the order, and (vi) countries to negotiate with. Subjects can send negotiating cards to more than one country at once. When the country that received the negotiating card accepts the proposal, a deal is made.

In the bilateral trading experiment, two types of sessions are conducted: the information of contract (contract time, the name of commodity, price, quantity, country name of the seller and the buyer) open session and the information of contract closed session.<sup>16</sup> However, negotiating processes between countries are closed even in the contract information open sessions.

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.

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<sup>14</sup> If a subject ends with over-compliance, we assign no value to any remaining permits.

<sup>15</sup> See Davis and Holt (1993: p. 41).

For example, if a country decides to reduce her emissions by a switch from using thermal power generation to using atomic power generation, it takes considerable time to construct atomic power plants, and hence the investment in the plants will take effect a few years after the decision. On the other hand, investment irreversibility means that although countries can increase capital level they cannot reduce it. For example, once a country constructs atomic power plants, she has to continue paying annual rental cost even if she decides to stop using them, since resale of the plants is impossible due to the fact that there is no use for atomic power plants except power generation.

In order to introduce these two features into the experiments, we apply diminishing return to scale emissions reduction function for each year  $t$  ( $=2008, \dots, 2012$ ):

$$Q(t) = AV(t)^{0.4}K(t)^{0.1}$$

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  $A$  the technical parameter different for each country. When we set variable cost per unit and rental cost per unit at \$1 for each country, long-run marginal abatement cost for each country at year  $t$  ( $LMC(t)$ ) is the following straight line:

$$LMC(t) = (1 / 0.1^{0.2} 0.4^{0.8} A^2) Q(t),$$

and short-run marginal abatement cost for each country at year  $t$  ( $SMC(t)$ ) is the following curve:

$$SMC(t) = K(t) + (1 / A^{2.5} K(t)^{0.25}) Q(t)^{2.5}.$$

When countries conduct emissions reduction at the optimal combination of variable input and capital, the ratio of variable cost to rental cost becomes four to one, which is almost the same as the ratio for power companies in developed countries.

We also introduce investment time lag and investment irreversibility into the emissions reduction function. When investment has  $L$  years of time lag,

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<sup>16</sup> In double auction, only contract information open sessions are conducted because all contracts as well as

$$K(t+L) = K(t) + I(t)$$

where  $I(t)$  is the level of investment at year  $t$ . In our experiment, we set  $L = 1$  for simplicity. In addition, investment irreversibility is expressed as follows:

$$K(t+1) \geq (1 - \delta(t))K(t)$$

where  $\delta(t)$  represents a depreciation rate at year  $t$ . For simplicity, we set  $\delta(t) = 0$  for each  $t$  in the experiment. Then we obtain the following inequality:

$$I(t) \geq 0.$$

Depending on the above rules, each subject faces the following schedule. First, in order to reduce the emissions at 2008, the first year of the five-year commitment period, each subject has to make an advance investment in 2007 ( $I(2007)$ ).<sup>17</sup> At the beginning of 2008, each subject decides the amount of emissions reduction ( $Q(2008)$ ) by determining the level of variable input ( $V(2008)$ ), and she may invest a certain amount of capital ( $I(2008)$ ) to increase the level of capital at 2009 ( $K(2009)$ ) for the emissions reduction in 2009 ( $Q(2009)$ ).<sup>18</sup> But the investment in 2008 ( $I(2008)$ ) has to be non-negative for investment irreversibility, so that she has to pay at least as much rental cost in 2009 as that in 2008 even if she does not reduce any emissions in 2009 ( $Q(2009)=0$ ). In 2008 through 2011, subjects may reduce their emissions in the year and also make an investment for reductions in the following year. However, they can no longer make an investment in 2012 because this investment will take effect in 2013, the year after the commitment period finishes. In our experiment, we focus only on the first commitment period, 2008 through 2012, so that investment for emissions reductions in 2013 is meaningless.

At the beginning of the year, each country anticipates the contract price for the year, plans emissions reductions of the year, and invests capital for the following year. After these decisions, each country trades emissions right or bonds for the whole year,

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orders are open by nature.

<sup>17</sup> We set  $K(2007) = 0$ . Therefore,  $K(2008) = K(2007) + I(2007) = I(2007)$ .

<sup>18</sup> Following the Kyoto Protocol, design is such that the emissions reductions of countries are known to other countries one year later.

behind which emissions reductions and capital investment are conducted according to the plan at the beginning of the year. Each subject is given ten minutes at the beginning of the year for the emissions reduction, investment, and prediction of the average level of contract price in the following twenty minutes, and after that, they are given twenty minutes to trade; one year consists of thirty minutes, so that the five-year commitment period takes two and a half hours.

We recruited a minimum of twelve students for each session through campus-wide advertisements at Osaka University. The students were told that there would be an opportunity to earn money in a research experiment (in the recruitment, no term was used peculiar to emissions trading). It took two days to conduct each experiment: instructions in the first day, and the execution of the sessions in the second day. In the first day, subjects listened to an experimenter reading instructions aloud, and practiced using a computer after a demonstration by the experimenter; total time was about four hours. In the second day, we chose ten participants in the two sessions by lot. Subjects who were not chosen were asked to leave the room with \$ 74.63 (\$1=134 yen). We randomly assigned ten country names (Japan, USA, Russia, Germany, France, UK, Rest EU, Eastern Europe, Australia-New Zealand, and Canada) to the ten subjects, who did not know which countries were assigned to the other subjects. Subjects were then given ten minutes to strategize before the first two and a half hour session started. After the first session finished, we informed subjects of the final state of the first session: holdings of emissions rights, holdings of bonds, amount of bond issue, amount of over- or under - compliance, and whether each subject made default or not. Then the second two and a half hour session started, where each subject was assigned the same country. It was not until the first session was completed that each subject knew that one more session would be conducted, so that each subject did not play the first session in an effort to influence the second session. Furthermore, although each subject knew that she was assigned the same country again in the second session, she did not know whether other subjects were also assigned the same countries, so that she could not take revenge on specific countries and/or repay specific countries for actions taken during the first session. The mean payoff per subject who participated in the second day was \$143.34 (maximum payoff was \$699.93, minimum payoff was \$97.01).

## **7. Intentional Bankruptcy in Buyer's Liabilities**

In our experiment, the profit achieved when subjects over-sold their bonds is different between the country-first and the Kyoto-first because although there is a penalty for not carrying out responsibility to the Kyoto Protocol there is no penalty for not fulfilling responsibility to other countries. In Kyoto-first, once countries hold as many emissions rights as they emitted, they can obtain a large profit by issuing and selling a large amount of bonds, which are not redeemed. In this case, first they retire as many emissions rights to the compliance committee as they emitted, which allows them to escape the penalty for non-compliance. Second, although they cannot carry out their responsibility to other countries since they do not have any emissions rights in hand, they do not have to pay penalties to other countries since the penalty for default is 0.

In country-first, on the other hand, when subjects sell a large amount of bonds which are not redeemed, they have to transfer all the emissions rights they hold to other countries first. After that, they cannot retire any permits to the compliance committee, so that they have to pay penalties for all the units they emitted. When they can obtain more revenue by over-selling than this non-compliance penalty, they can achieve a certain profit, but this profit is smaller than that in the Kyoto-first. Therefore, we conjectured that intentional bankruptcy would occur more frequently in Kyoto-first than in country-first; this is statistically tested in the next section.

Each country, however, will not necessarily be able to over-sell her bonds. When subjects notice over-selling, they may decide not to buy bonds issued by her, or the price of the bonds may drop considerably, which can make the profit from over-selling smaller than the profit obtained when over-selling is not performed. Therefore, we conjectured that the more open the information on the other subjects is, the less frequently intentional bankruptcy would occur. Thus in our experimental setting, intentional bankruptcy may occur more frequently in the contract information open sessions than in the contract information closed sessions. We also test this statistically in the next section.

## **8. Results in Experiment 3**

### **8.1 Analyses with Efficiency Table**

In this section we analyze experimental results using Efficiency Tables 4, 5 and 6, which provide a summary of the sessions.

In the tables the top row indicates the name of the sessions. To abbreviate the names of sessions, we denote the seller's liability by S, the country-first buyer's liability by C, the Kyoto-first buyer's liability by K, double auction by D, bilateral trading with contract



information open by Bo, bilateral trading with contract information closed by Bc, first session by 1, and second session by 2. Therefore, SBc2 represents the second session of seller's liability and information closed bilateral trading experiment. The left column shows the country name and the position each country starts the experiment with: for example, JPN starts the experiment with 371 units of under-compliance and RU with 1133 units of over-compliance (with 1133 units of hot air). From the second column, the upper figure in each cell is the efficiency of the subject and the lower figure is the position the subject ends the session with. For example, GER in SD1 (the first double auction session with the seller's liability) attained efficiency 0.594 and ended with 30.1 units of non-compliance, and UK in the same session attained efficiency -4.683 and ended with 13.5 units of over-compliance. Gray shading in the cell indicates bankruptcy, or default, and a bold square around the cell indicates the bankruptcy is intentional, so that a cell with gray shading and without a bold square indicates a chain reaction bankruptcy caused by other subject's bankruptcy.<sup>19</sup> The bottom two rows of the table show the market efficiency and the sum of over-compliance. In "Seller, D1", for example, the market efficiency is 0.512 and the amount of over-compliance as a whole was 463.8 units.

In order to demonstrate which is the superior buyer's liability rule, we first compare efficiencies of country-first and Kyoto-first liabilities.

**Result 7.** *On average country-first buyer's liability can attain higher efficiency than Kyoto-first buyer's liability.*

*Support.* The mean of the efficiency of the country-first buyer's liability sessions is statistically higher than that of the Kyoto-first buyer's liability sessions at the 5% significant level. ■

When we compare the seller's liability and the country-first, or the superior buyer's liability, we obtain the following two results:

**Result 8.** *A difference between the efficiency of seller's liability and that of country-first buyer's liability was not observed.*

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<sup>19</sup> We consider the bankruptcy of country  $i$  to be intentional when  $R_i + \sum_j B_{ji} < \sum_i B_{ij}$  before any other country results in bankruptcy.

*Support.* The difference of the mean of the efficiency of seller's liability sessions and that of the country-first buyer's liability sessions is statistically insignificant. ■

**Result 9.** *The variance of the efficiency of the seller's liability is larger than that of the country-first buyer's liability.*

*Support.* The mean of the variance of the efficiency of seller's liability sessions is statistically larger than that of the country-first buyer's liability sessions at the 10% significant level. ■

That is, although the average efficiencies of the seller's liability and the country-first are not so different, the session in seller's liability is likely to result in extremely high efficiency or extremely low efficiency compared to the country-first, which is later confirmed by the scatter diagram of the sessions.

Next, we compare the frequencies of intentional bankruptcy.

**Result 10.** *Intentional bankruptcy occurs more frequently in the Kyoto-first buyer's liability than in the country-first buyer's liability.*

*Support.* The mean of the number of the countries which results in intentional bankruptcy in the Kyoto-first buyer's liability is statistically larger than that in the country-first buyer's liability at the 5% significant level. ■

However, the difference for the frequencies of intentional bankruptcy between contract information open session and closed session is insignificant.

## **8.2 Classification of the Sessions by their Dynamic Processes**

Since Tables 4, 5 and 6 do not give us the dynamic processes of transactions and expectations about the average level of contract price as time passes, we use figures where these dynamic processes are illustrated with the path of the point equilibrium price, the market-clearing price at each point of time. As an example, see Figure 10, the figure of session SBo2. In this figure, the vertical axis represents price, and the horizontal axis represents minutes, where five periods for emissions reduction and investment are compressed into the beginning of the respective trading periods 0, 20, 40, 60 and 80.

Squares in the figure show transactions. The gray (or green) horizontal line shows the competitive equilibrium price 67. The black (or dark brown) line represents the point equilibrium price path. It starts from competitive equilibrium price 67, then becomes about 70 in the first twenty minutes, about 68 in the second twenty minutes, about 61 in the third twenty minutes, about 65 in the fourth twenty minutes, and 0 in the last twenty minutes. The gray (or red) triangles represent expectations by subjects about the average level of contract price in the following twenty minutes, and dotted gray (or red) line represents the means of the expectations.

By comparing these figures for each session it is observed that the pattern of the point equilibrium price path and the mean expectation path varies considerably from session to session: in some sessions the mean expectation is consistently higher than the point equilibrium price and in others they are almost the same. That is, sessions are characterized by their pattern of the point equilibrium price path and the mean expectation path. As a measure of these path patterns we introduce the concept of *degree of bubble*, which is the sum of the differences between the point equilibrium price and the mean expectation of the average level of contract price for each year. This measure becomes positive (negative) when subjects continue expecting higher (lower) contract price than the theoretical market-clearing price, or the point equilibrium price; therefore this measure represents the degree of the bubble. In Figure 10, the point equilibrium price and the mean expectation of the average level of contract price are almost the same in each year, so that the degree of bubble is almost zero. In Figure 11 (session SD2), on the other hand, although the point equilibrium price dropped early, the mean expectations of contract price are high, so that the degree of bubble is large.

According to this new concept and market efficiency, we obtain the following results.

**Result 11.** *The sessions are grouped into four, that is, (i) sessions SD1, SBo2, SBc1, SBc2, CD2, CBo1, CBo2, CBc1, KD1 and KD2, (ii) sessions SD2, SBo1, CD1 and KBo1, (iii) sessions CBc2 and KBo2, and (iv) sessions KBc1 and KBc2.*

*Support.* After normalizing the efficiency and the degree of bubble, we use cluster analysis to classify the sessions. The eighteen sessions are then divided into four groups, i.e., (i) sessions SD1, SBo2, SBc1, SBc2, CD2, CBo1, CBo2, CBc1, KD1 and KD2, (ii) sessions SD2, SBo1, CD1 and KBo1, (iii) sessions CBc2 and KBo2, and (iv) sessions KBc1 and KBc2. ■

The dynamic characteristics of each group are as follows. First, Figure 10 (session SBo2) is an example from the first group, i.e. sessions SD1, SBo2, SBc1, SBc2, CD2, CBo1, CBo2, CBc1, KD1 and KD2. In this session, although almost all contract prices were lower than the point equilibrium price, in each year the mean expectation of the average level of contract price was almost the same as the point equilibrium price; that is, each country anticipated the correct market-clearing price. Therefore they conducted optimum emissions reductions, which makes the efficiency of the session high. This type of dynamic process also applies to the other sessions that belong to this group. That is, the mean expectation of the average level of contract price was almost the same as (or a little higher than) the point equilibrium price, so that each country conducted optimum emissions reduction, which makes efficiency high. We termed this group "the success case".

Figure 11 (session SD2) is an example from the second group, i.e. sessions SD2, SBo1, CD1 and KBo1. In this session all the countries predicted a higher price than the competitive equilibrium price 67 at the beginning of the session, so that they conducted excessive emissions reduction and the point equilibrium price dropped from 67 to about 50; that is, the market-clearing price in the first year became about 50. However, contract prices in the first year were considerably higher than 50. Seeing these contract prices, all subjects anticipated a higher price than the point equilibrium price at the beginning of the second year. They then conducted further excessive emissions reductions, which made the point equilibrium price drop further. However, contract prices in the second year were still high due to inertia of contract price. These high expectations of price, excessive reductions, and the drop of point equilibrium price were repeated in the third and the fourth year. In the fourth year the point equilibrium price dropped to 0; that is, even if no country conducts emissions reductions in the fifth year, the sum of the emissions rights exceeds the sum of emissions. In the last year the contract price crashed and finally it was equalized to the point equilibrium price. Efficiency of the session was extremely low because inefficient emissions reductions were repeated. This type of dynamic process also applies to the other sessions that belong to this group. That is, at the early stage expectation of high price caused subjects to conduct excessive emissions reduction and, accordingly, the point equilibrium price dropped. However, contract prices were extremely high reflecting high expectations, and due to inertia contract prices did not drop immediately. Therefore subjects continued reducing their emissions excessively, which caused the point

equilibrium price to decrease even further. This cycle caused great efficiency losses. We termed this group "the bubble case".

Figure 12 (session CBc2) is an example from the third group, i.e. sessions CBc2 and KBo2. In this session more than half of the countries predicted a lower price than the competitive equilibrium price at the beginning of the session, so that the sum of the emissions reductions was smaller than the sum of the optimum reductions, which made the point equilibrium price rise from 67 to about 69. However, contract prices in the first year were a little lower than 69. Seeing these contract prices, almost all subjects anticipated a lower price than the point equilibrium price at the beginning of the second year. They then again conducted insufficient emissions reductions, which made the point equilibrium price rise further. However, contract prices in the second year were still low due to inertia of contract price. These low expectations of price, insufficient reductions, and the rise of point equilibrium price were repeated until the last year. In the last year the point equilibrium price rose to 250, the penalty for non-compliance, because the sum of the emissions exceeded the sum of emissions rights. Efficiency of the session was low because inefficient emissions reductions were repeated. This type of dynamic process also applies to the other session that belongs to this group, KBo2. That is, at the early stage expectation of low price caused subjects to conduct insufficient emissions reduction and, accordingly, the point equilibrium price rose. However, contract prices were still low reflecting low expectations, and due to inertia contract prices did not rise immediately. Therefore subjects continued reducing their emissions insufficiently, which caused the point equilibrium price to rise even further. This cycle caused great efficiency losses. We termed this group "the anti-bubble case".

Figure 13 (session KBc1) is an example from the fourth group, i.e. sessions KBc1 and KBc2. In this session, four countries resulted in intentional bankruptcy. Although the prices of their issued bonds became almost 0 around the middle stage of the session, the prices of bonds issued by Russia (diamonds in the figure) remained high because she started the session with over-compliance and was less likely to result in bankruptcy. In this session many countries continued conducting excessive emissions reductions although contract prices and expectations of price were not much higher than the point equilibrium price. This phenomenon is explained by the following. In KBc sessions, although over-selling is profitable due to the Kyoto-first rule, it is hard to determine which subjects are over-selling their bonds because of the closed information. Therefore, demander's countries

in the session tried to attain their targets by themselves through conducting excessive domestic reductions, which made the point equilibrium price drop. This type of dynamic process also applies to the other session that belongs to this group, KBC2. We termed this group "the intentional bankruptcy case".

Figure 14 shows a scatter diagram of the 18 sessions, where the horizontal axis represents efficiency and the vertical axis represents the degree of bubble. The visual impression given by the figure confirms the cluster analysis described above. In addition, we notice that the sessions in the seller's liability are likely to result in extremely high efficiency or extremely low efficiency compared to the country-first as mentioned.

In Figure 15, we add to Figure 14 a third axis, the sum of over-compliance. We notice that the sum of over-compliance in the bubble case is larger than that in the success case, which indicates that from the viewpoint of environmental integrity the bubble case is superior to the success case, although from the economical viewpoint the reverse is true. In the anti-bubble case, the sum of over-compliance is negative as well as having a low efficiency, so that the anti-bubble case is inferior to the success case. In the intentional bankruptcy case, the sum of over-compliance is lower than that in the bubble case, although the efficiency is almost the same, so that the intentional bankruptcy case is inferior to the bubble case.

## 9. Concluding Remarks

Experiments 1 and 2 show that uncertainty in investment, such as irreversibility and time lag, plays an important role in terms of efficiency of emissions trading. Although the efficiency of experiments in Experiment 1 is high, two types of price dynamics were observed in Experiment 2. In the constant point equilibrium price case, relatively low prices at an early stage caused insufficient emissions reduction by suppliers, and demanders therefore conducted excessive reductions immediately before the end of the investment period. Efficiency was relatively high in this case. On the other hand, in the early point equilibrium price decrease case, due to fear of non-compliance some subjects conducted excessive domestic reductions at an early stage of the transactions, and hence the point equilibrium price dropped, although contract prices did not drop immediately because of price inertia. The efficiency of this pattern was relatively low. In each pattern, the modified efficiency of double auction sessions was higher than that of bilateral trading, however this

does not necessarily imply that double auction is more effective than bilateral trading since only one double auction session belongs to the constant point equilibrium price case where modified efficiency is higher than that of the early point equilibrium price decrease case.

Experiment 3 shows that the introduction of liability changes the whole picture. Depending on the order of liability, we have two liability systems: the “country-first” liability system and the “Kyoto-first” liability system. Under these systems we have two new cases in addition to the two cases in Experiment 2: the anti-bubble case and the intentional bankruptcy case. The former appears when we introduce country-first liability and the latter appears when we introduce Kyoto-first liability. We found that it is hard to determine which is better between seller’s liability and country-first liability, although both are superior to Kyoto-first liability.

It is not easy to determine policy implications from the results of these experiments, but it seems that a strategy based on "carrying out reduction investment by immediately responding to the market price" was not successful. Rather, it seems that a party should *gradually* purchase emissions permits if the market price is cheaper than the marginal abatement cost, and it should *gradually* carry out abatement investment otherwise. In order to verify this statement, however, further experiments are needed.

Experimental economists have found that double auction is one of the best institutions for trading. However, in an environment incorporating investment decisions explicitly it seems that double auction is not always the best institution. For example, in bilateral trading, the market price does not move in one direction since information such as price and quantity is not centralized and it takes a considerable amount of time for it to be disseminated to participants. Further study is also needed on this matter.

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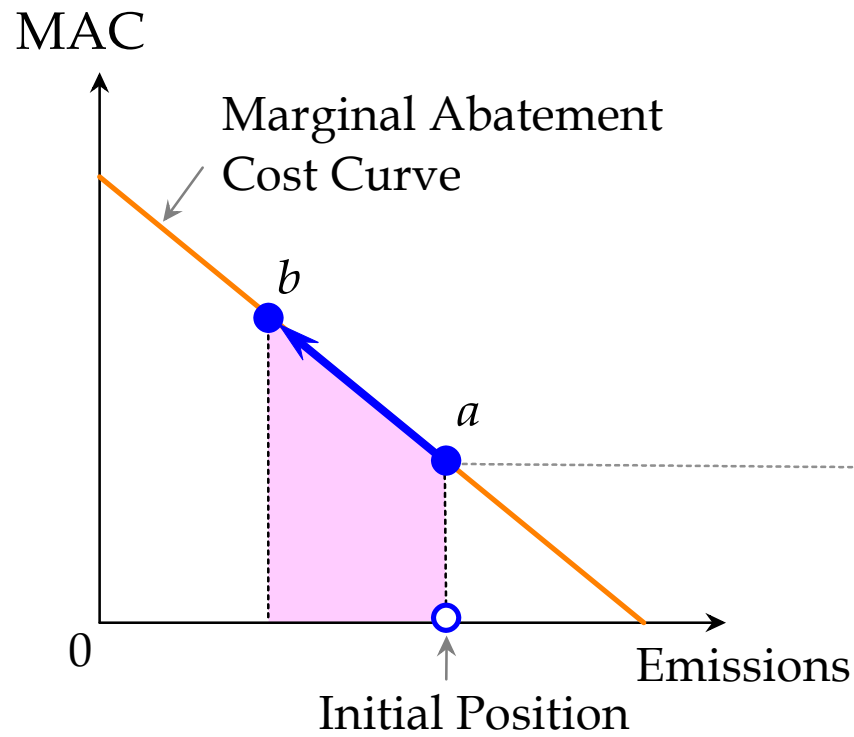


Figure 1-1

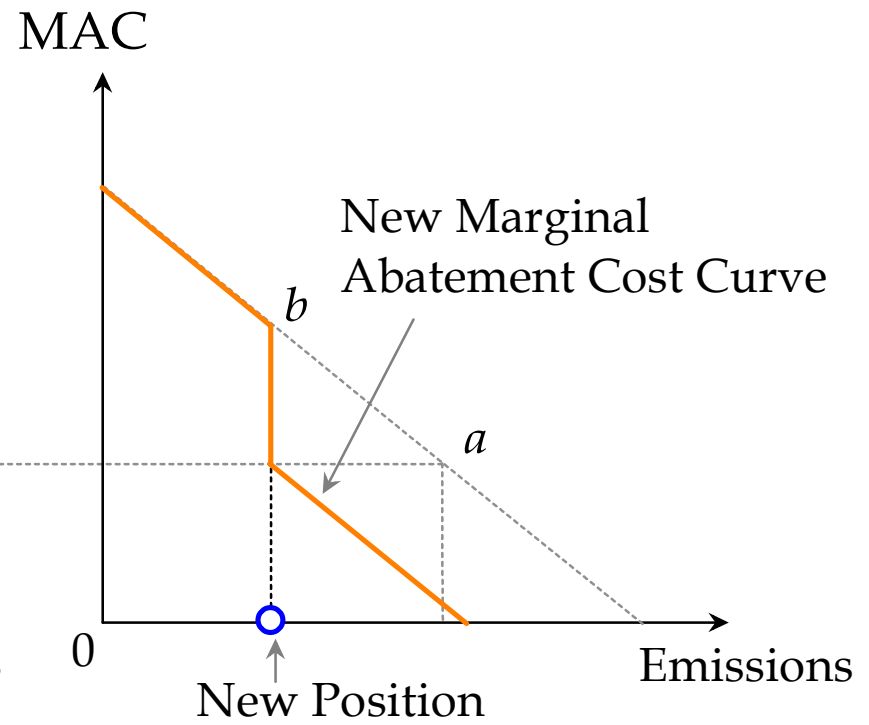


Figure 1-2

Figure 1. Abatement Irreversibility in Experiment 2

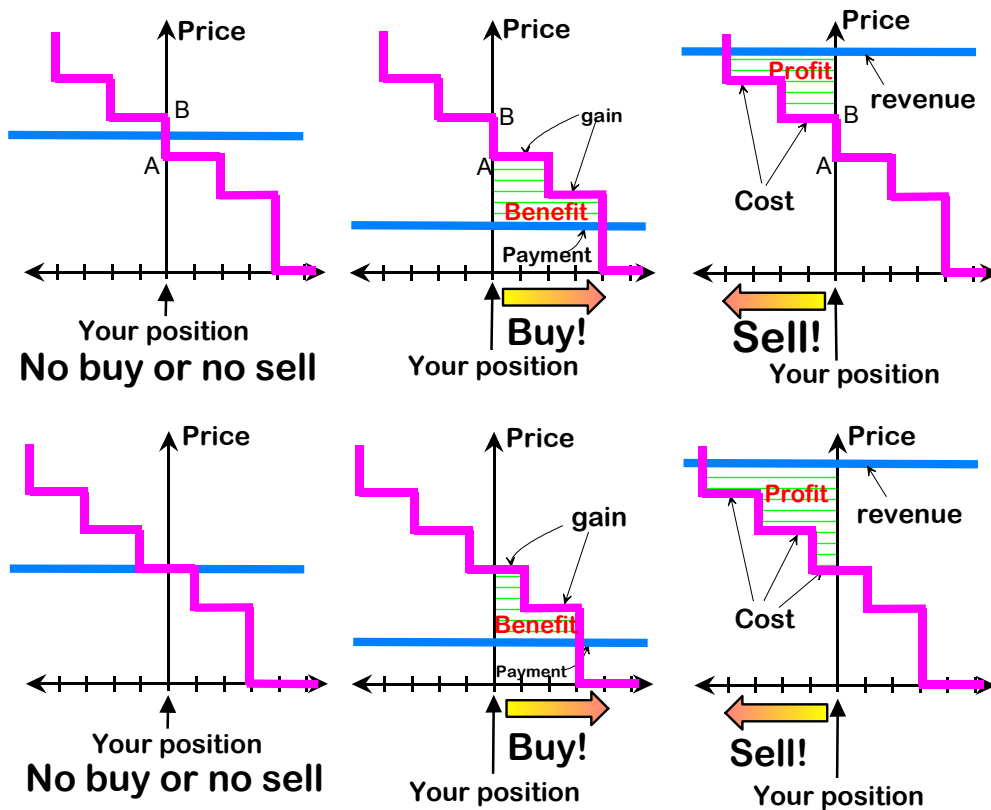
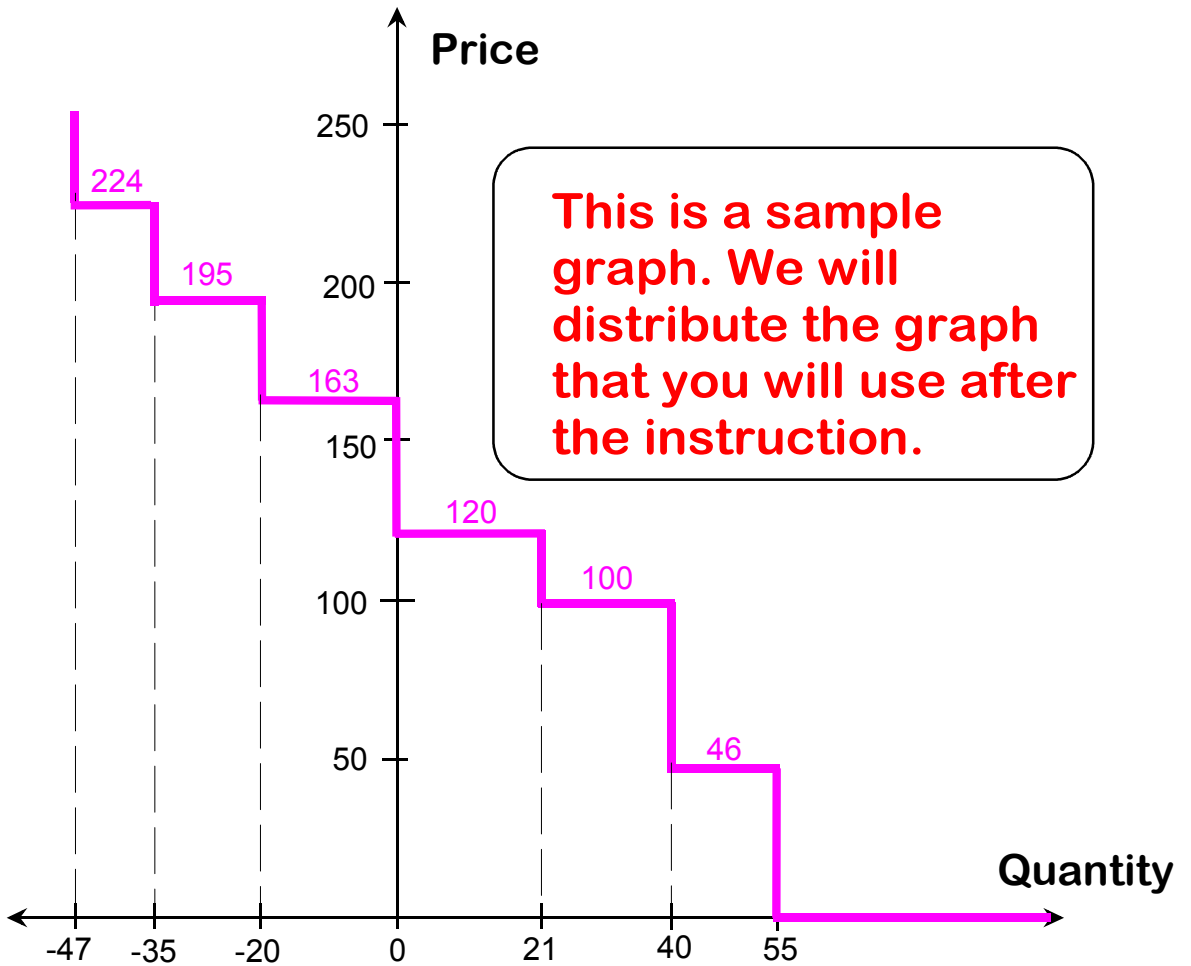


Figure 2-1. A Sample Graph in Experiment 1

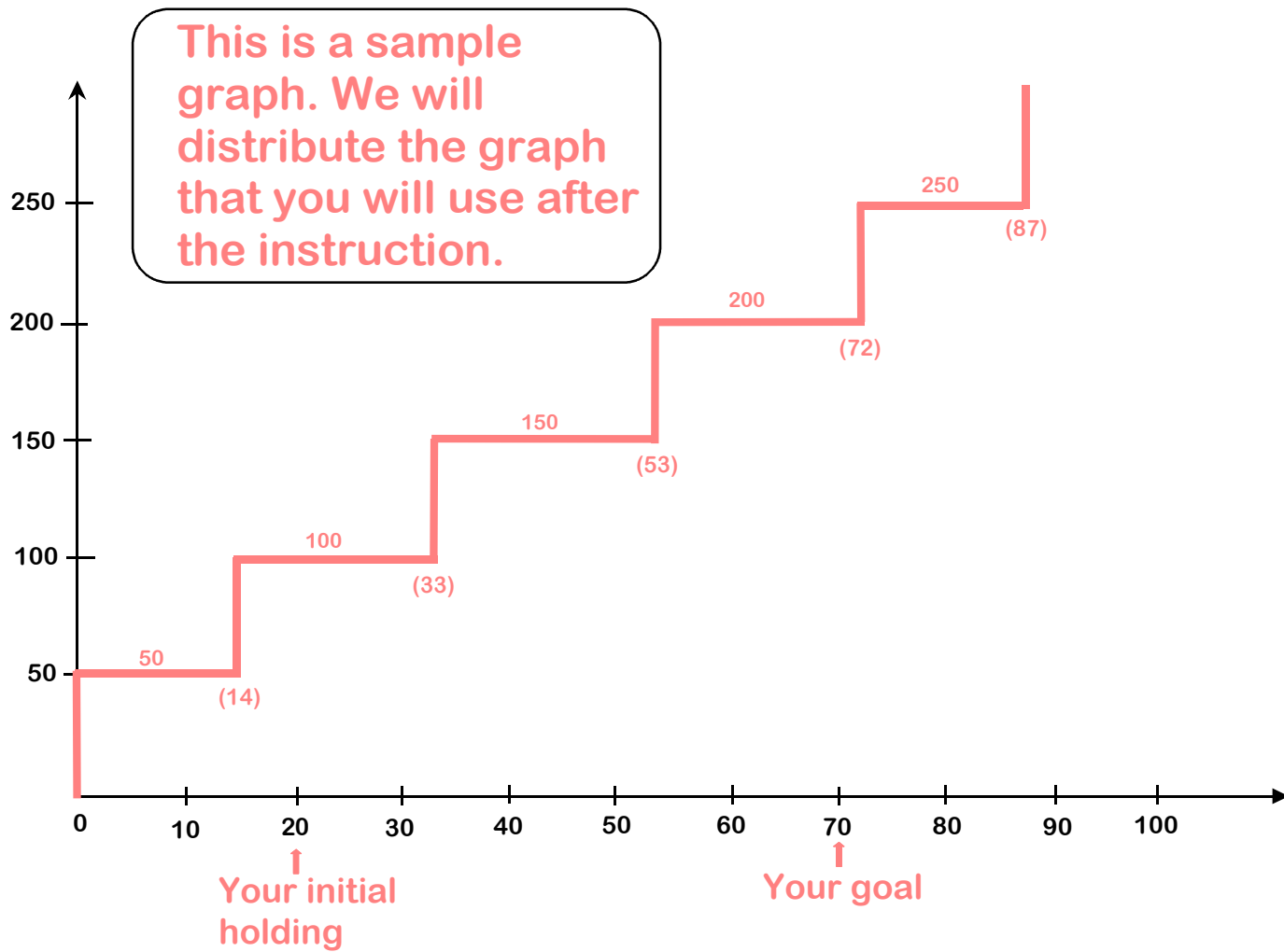


Figure 2-2. A Sample Graph in Experiment 2

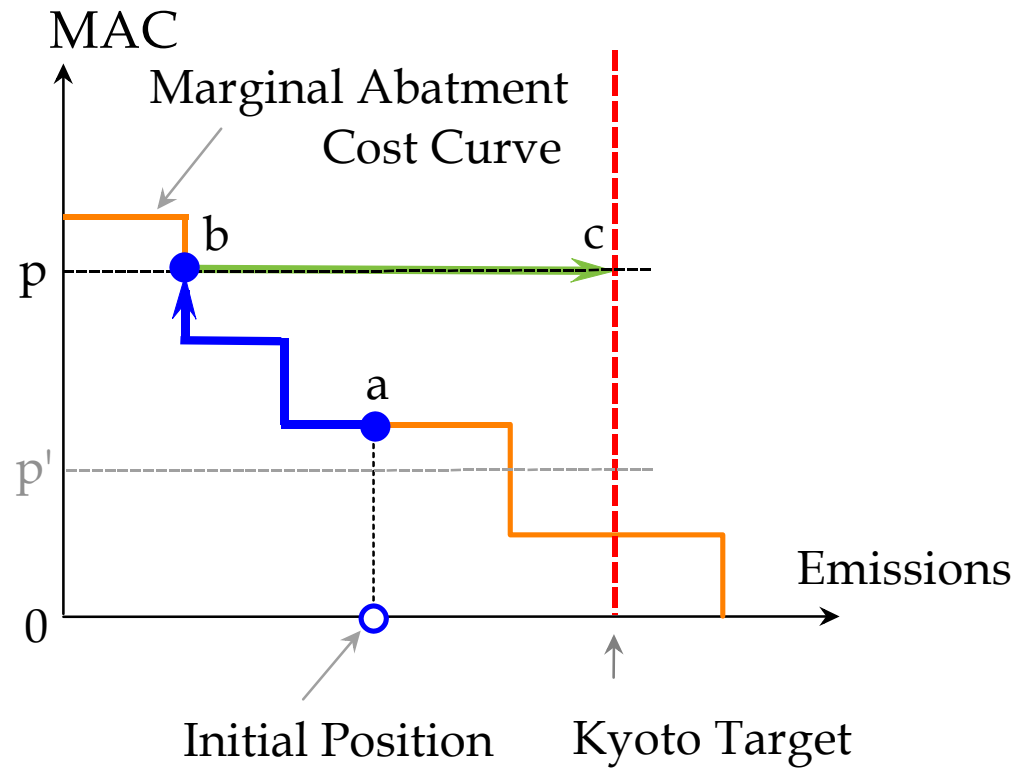
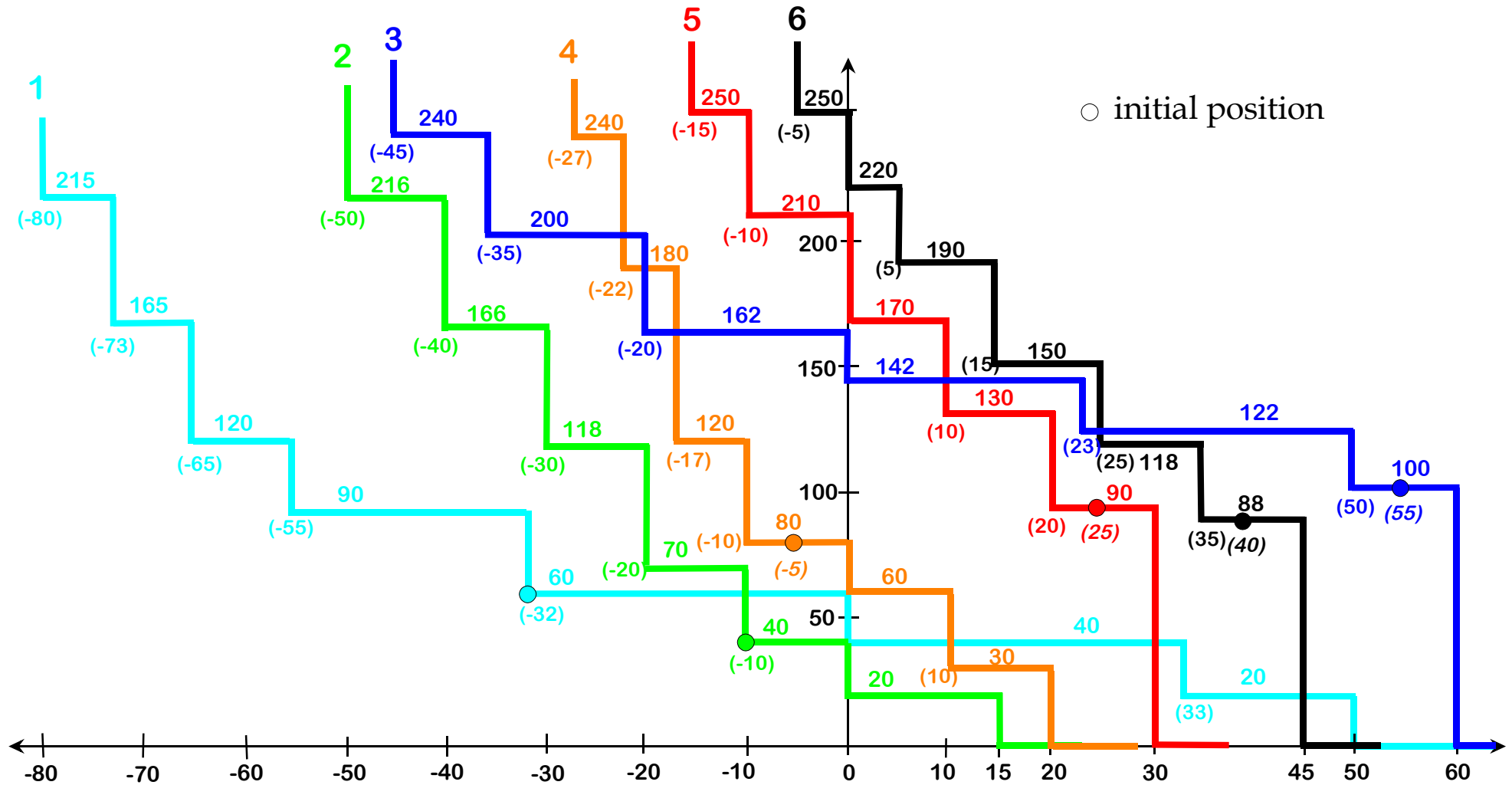


Figure 3. A Possible Strategy in Experiment 2

1-Russia 2-Ukraine 3-USA 4-Poland 5-EU 6-Japan



No country names were given to subjects in the experiment.

Figure 4. All Marginal Abatement Cost Curves in Experiment 1 and 2

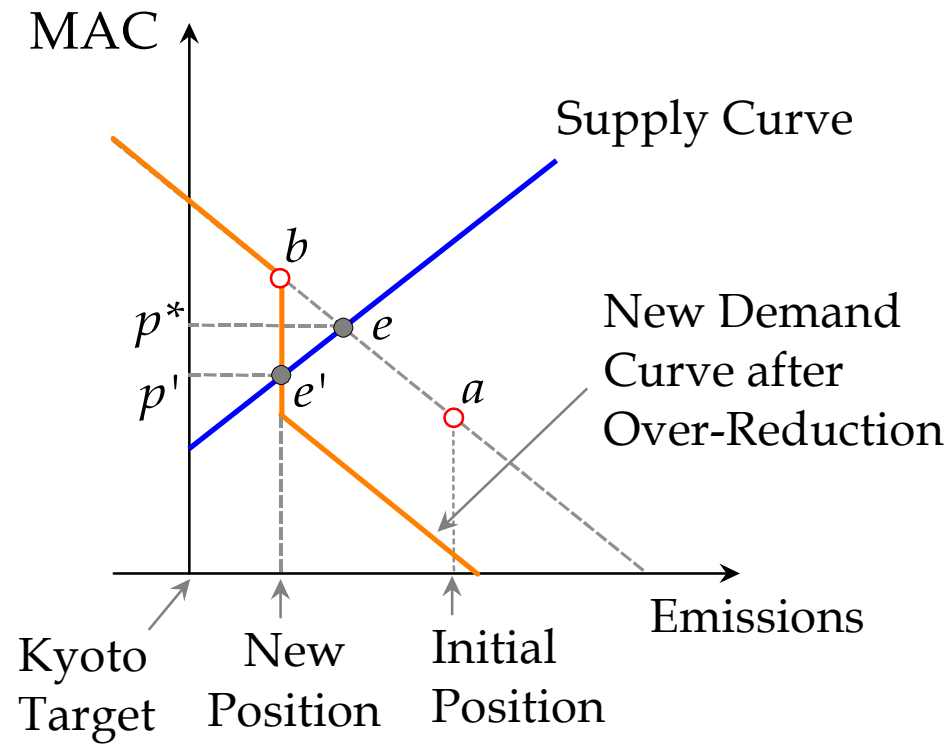


Figure 5. Point Equilibrium in Experiment 2

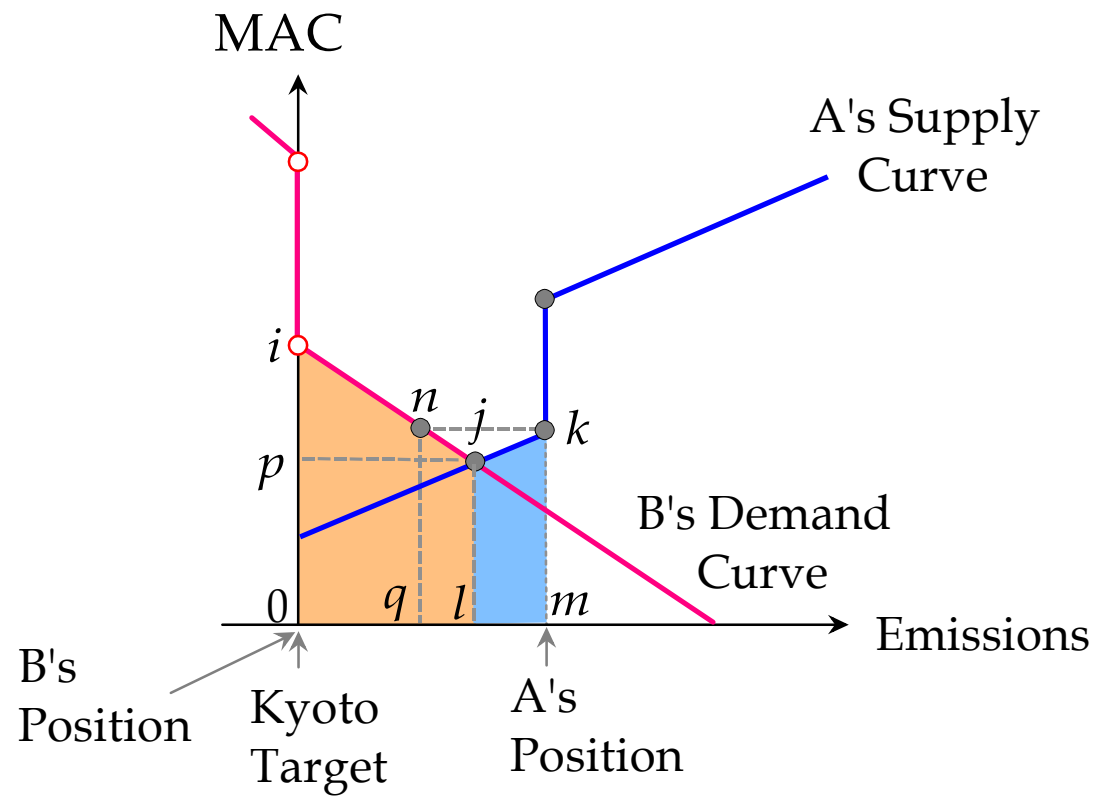


Figure 6. Re-evaluation of Permit Surplus in Experiment 2

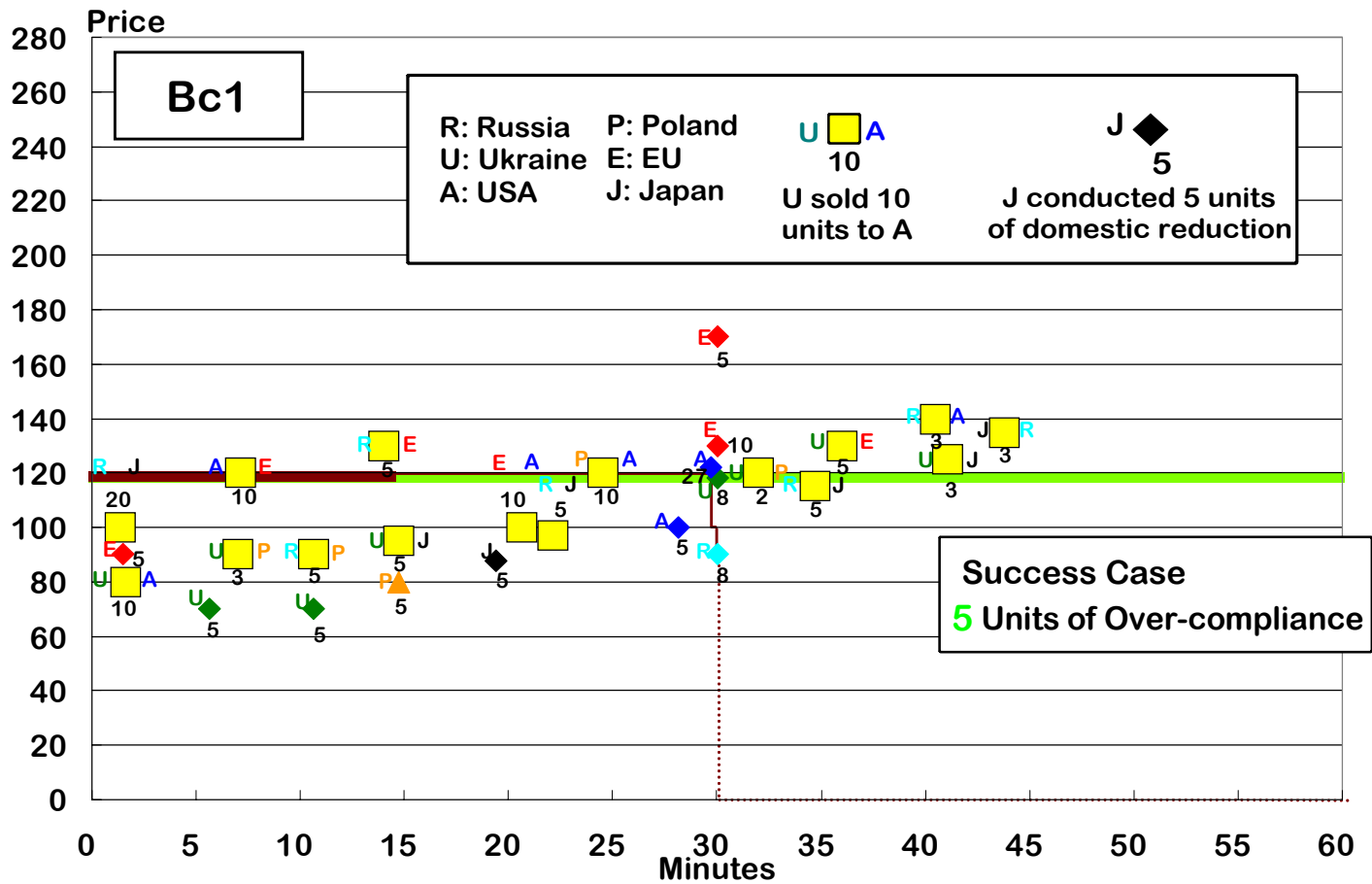


Figure 7. Success Case in Experiment 2



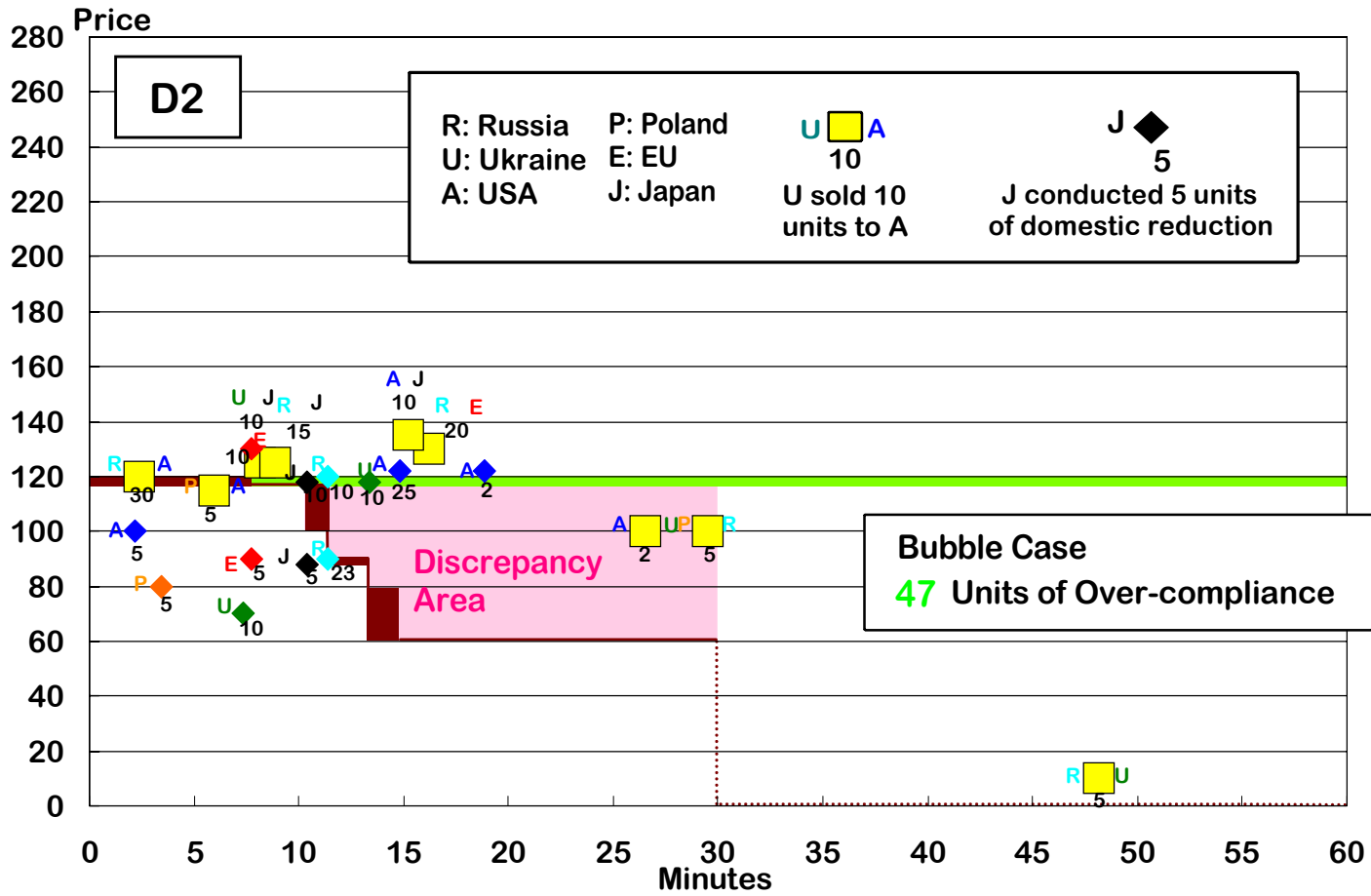


Figure 8. Bubble Case in Experiment 2

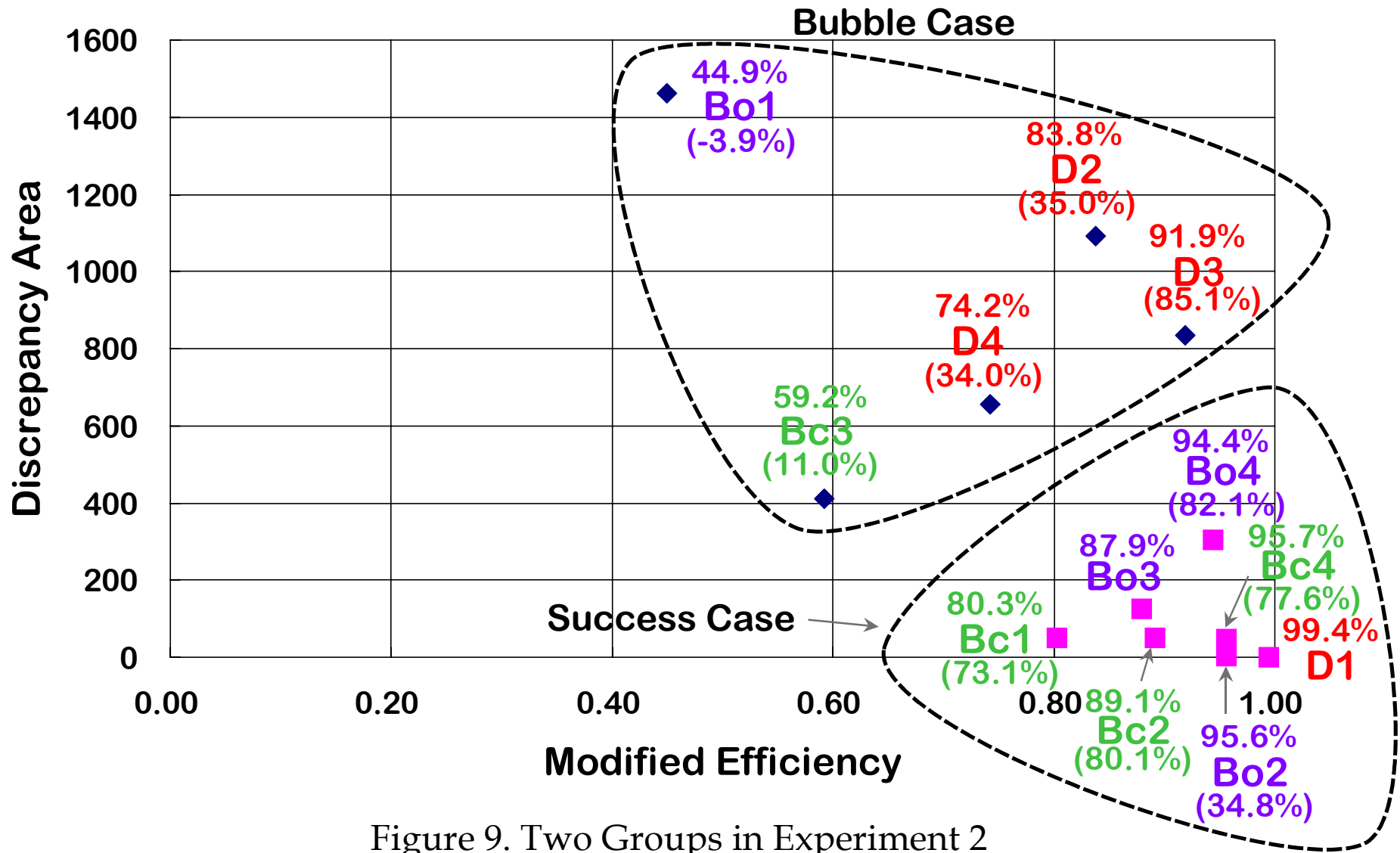


Figure 9. Two Groups in Experiment 2

### Seller's Liability, Bilateral Trading, Information Open, Second Session

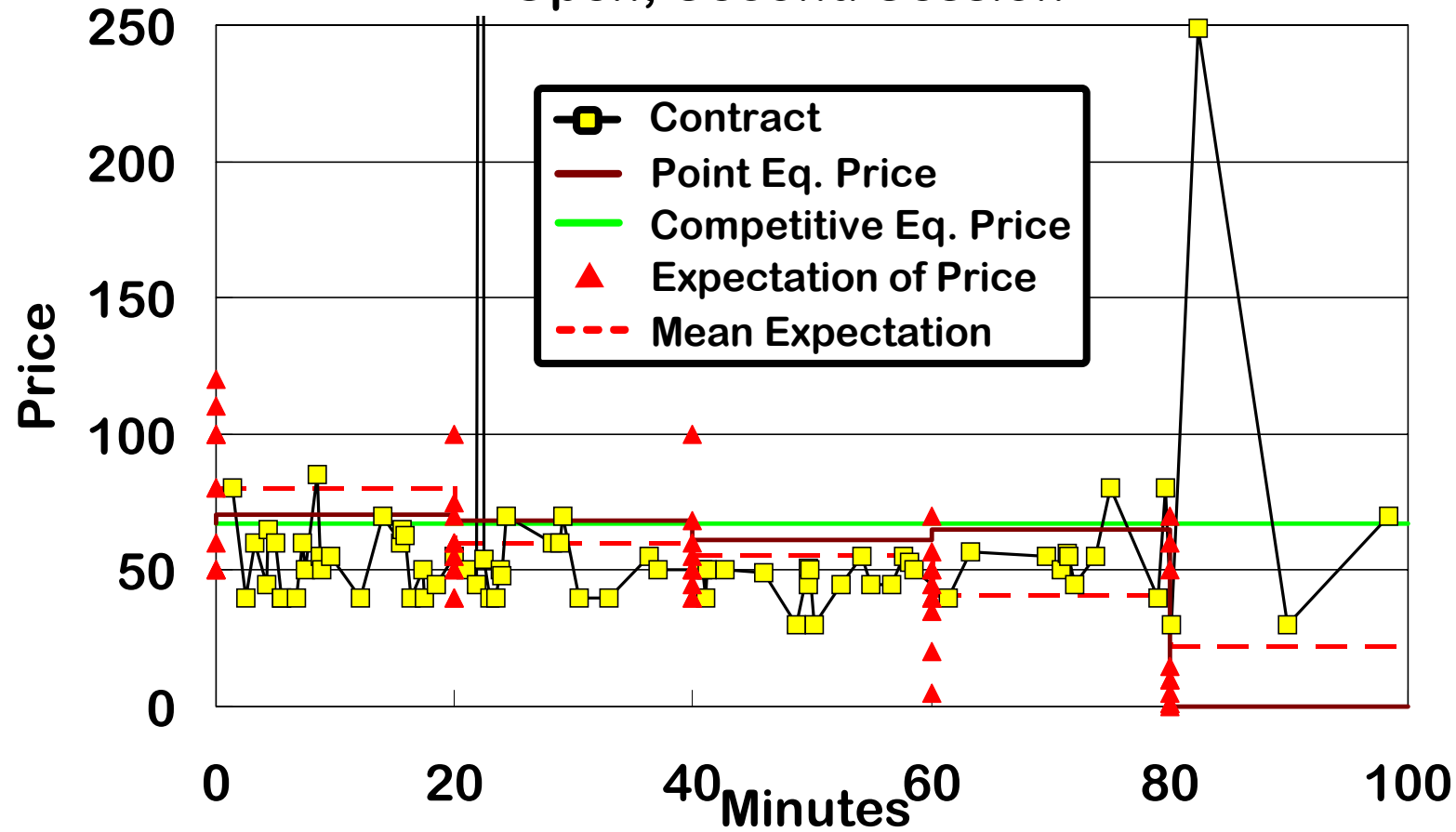


Figure 10. Success Case in Experiment 3

# Seller's Liability, Double Auction, Second Session

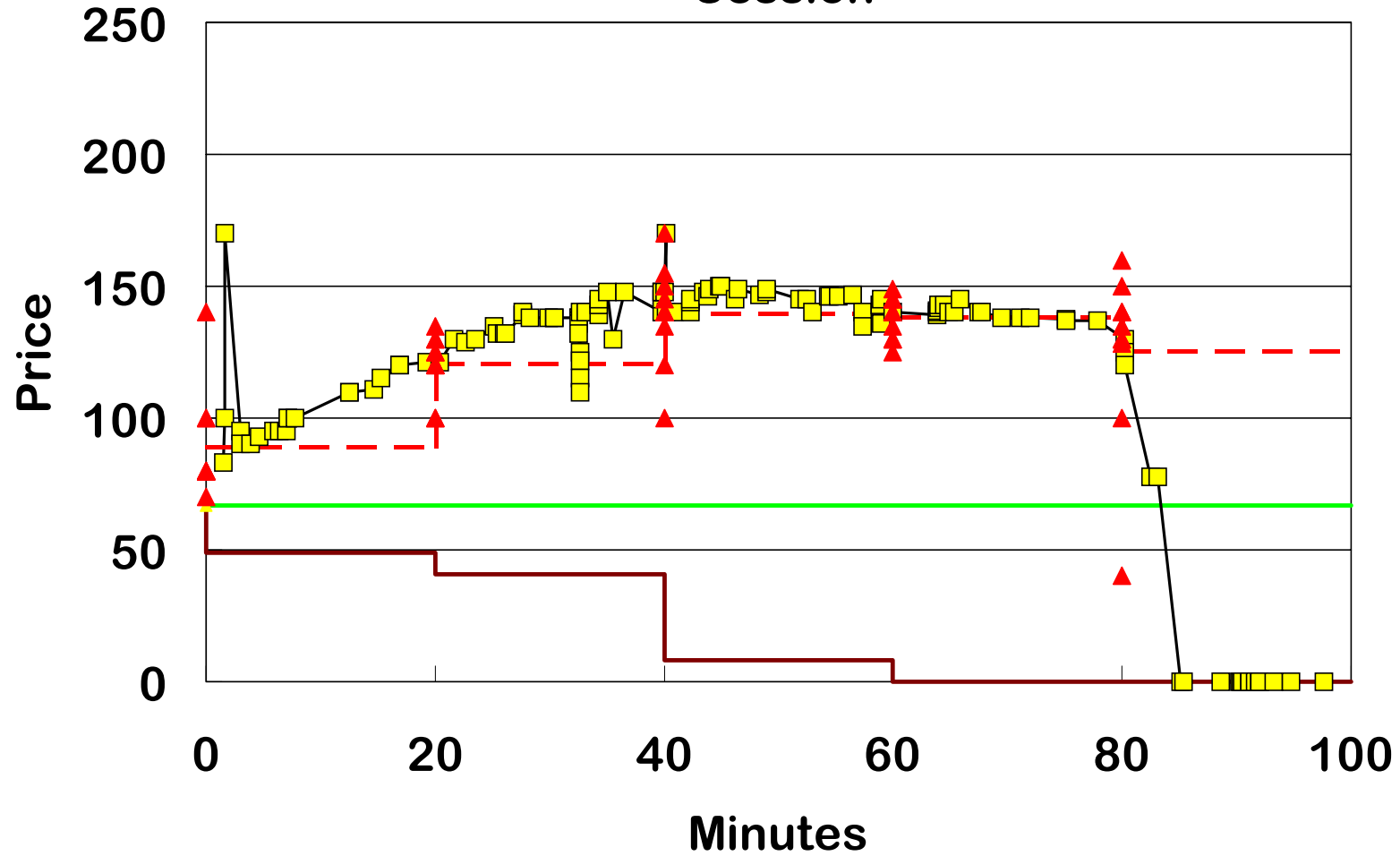


Figure 11. Bubble Case in Experiment 3

### Country First, Bilateral Trading, Information Closed, Second Session

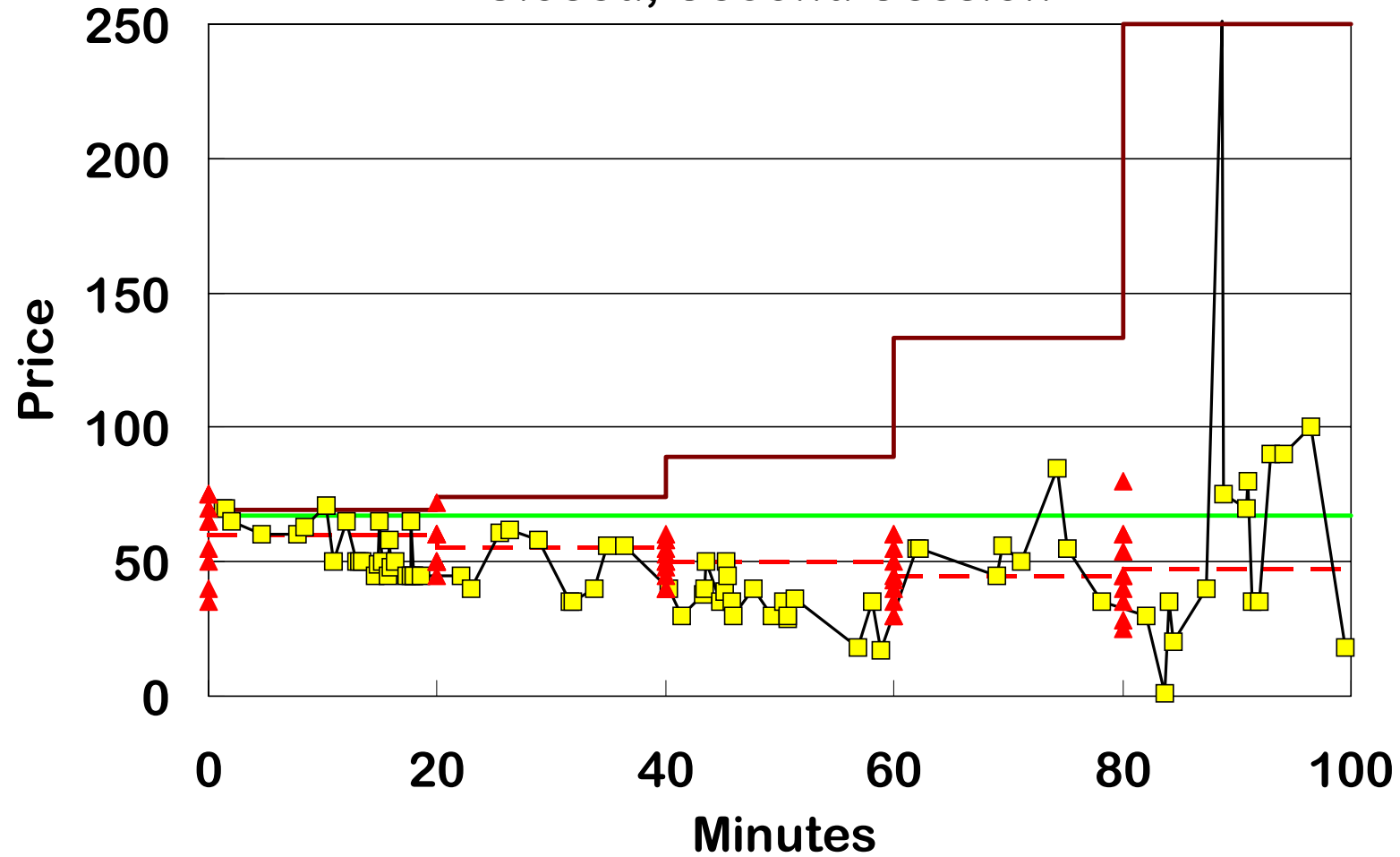


Figure 12. Anti-bubble Case in Experiment 3

### Kyoto First, Bilateral Trading, Information Closed, First Session

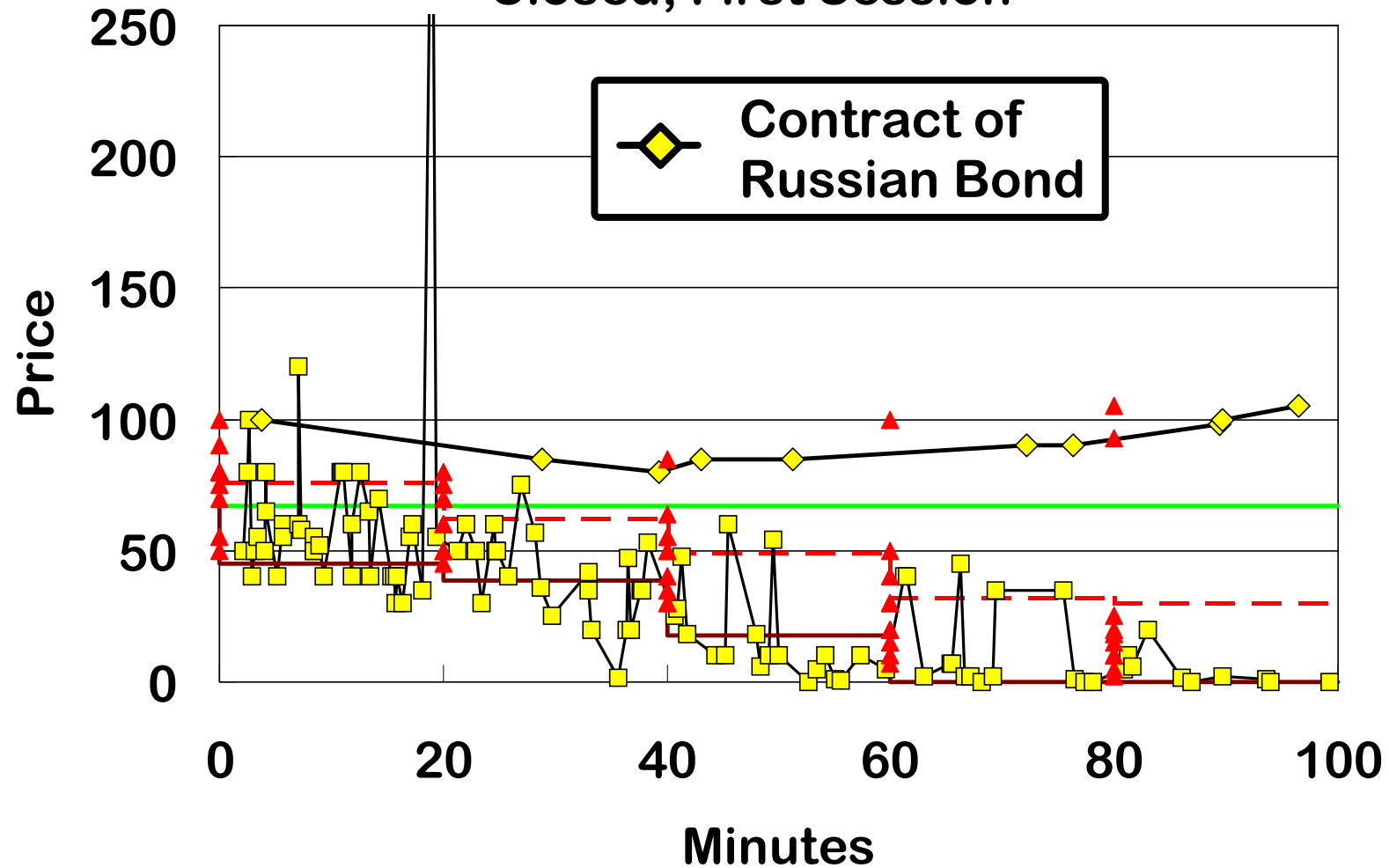


Figure 13. Intentional Bankruptcy Case in Experiment 3

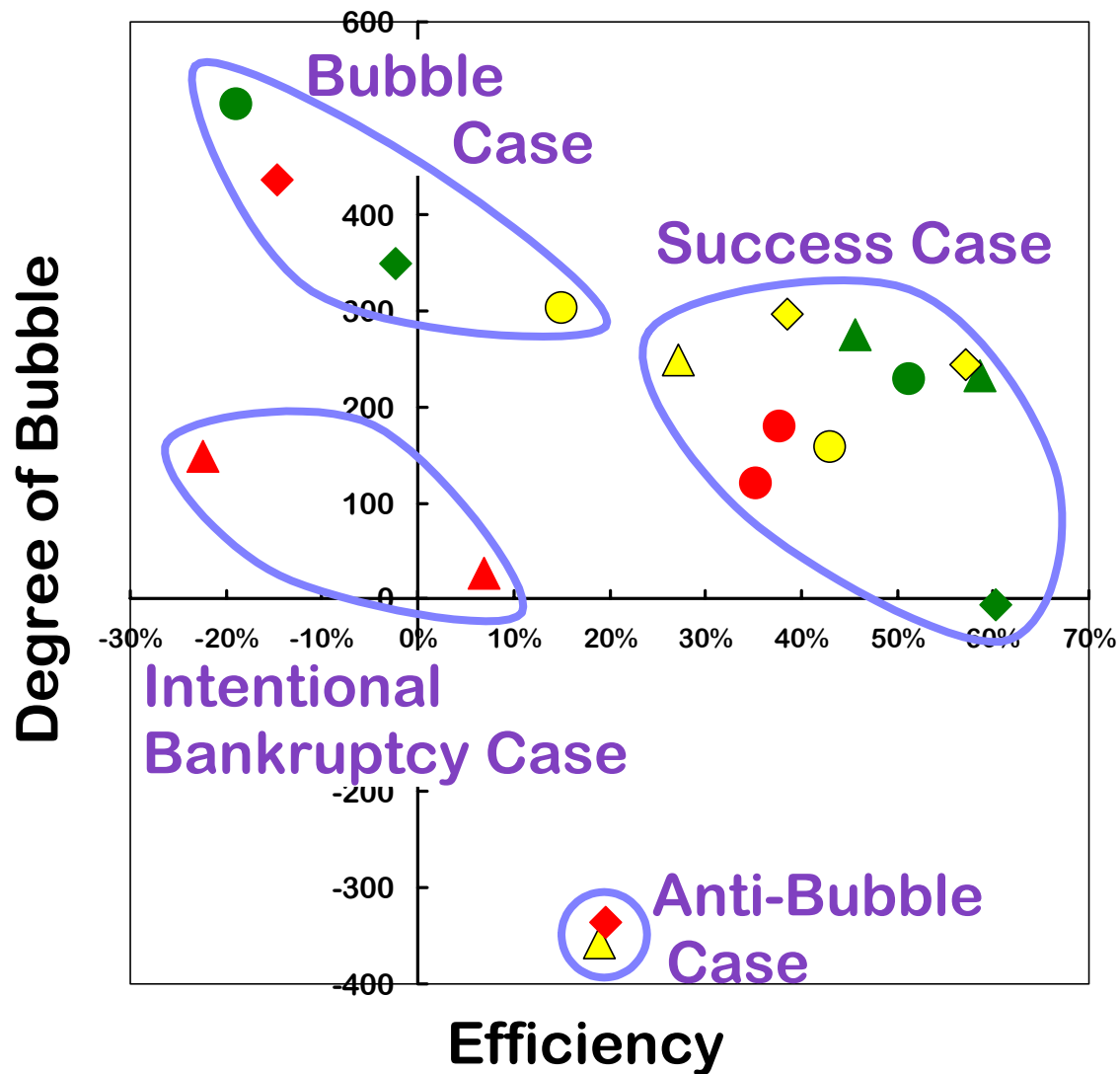


Figure 14. Four Groups in Experiment 3

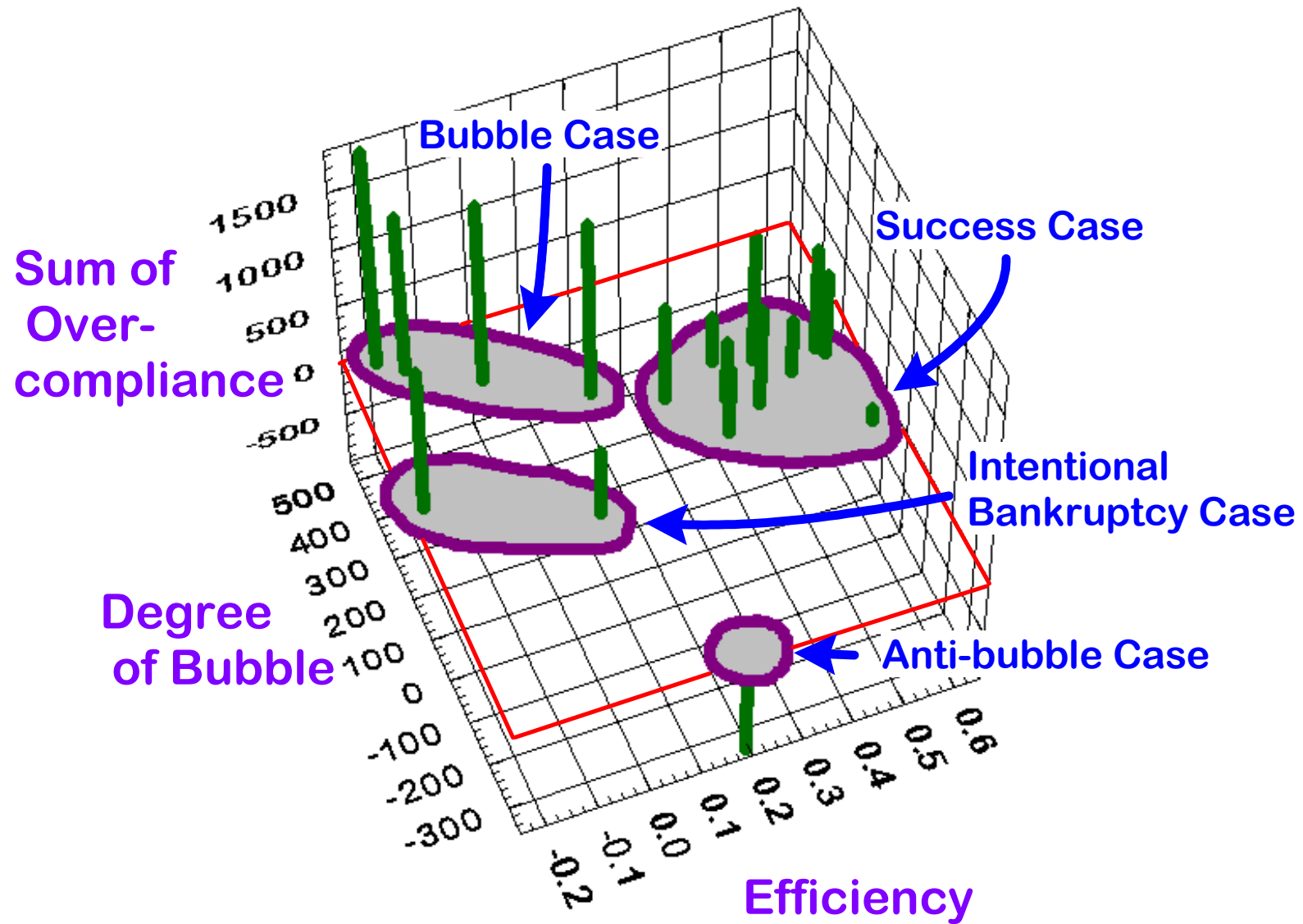


Figure 15. Sum of Over-compliance in Experiment 3



	SD1	SD2	SBo1	SBo2	SBc1	SBc2
JPN	3.830	-1.470	0.063	-1.207	-0.177	-1.642
-371	0.0	0.0	79.0	0.0	10.7	344.2
USA	-3.655	-0.751	0.388	1.196	0.451	0.546
-3,162	0.0	1227.3	0.0	0.8	9.0	18.3
RU	1.891	1.538	0.698	0.623	1.417	1.178
1,133	0.0	0.0	61.0	0.0	146.6	0.0
GER	0.594	-4.378	-2.595	-0.412	1.498	1.553
-234	-30.1	0.0	135.0	0.0	0.0	0.0
FR	59.639	-9.114	-3.767	-9.116	1.592	0.940
-59	0.0	11.0	0.2	249.2	0.0	0.0
UK	-4.683	-25.409	-17.019	-7.073	-0.759	-0.786
-151	13.5	142.0	768.0	-190.0	82.0	100.0
RestEU	5.662	3.462	-1.449	0.967	-8.015	-1.220
-350	480.4	0.0	124.7	-1.0	850.0	70.0
EER	-0.220	-0.059	1.306	0.615	1.065	0.714
87	0.0	457.0	60.0	20.0	0.0	100.0
AU_NZ	-4.315	-1.715	-14.545	0.948	-11.667	-4.811
-149	0.0	0.0	217.0	5.0	0.0	61.9
CAN	0.480	0.681	-0.387	6.369	0.728	1.232
-208	0.0	0.9	104.6	28.7	1.4	0.0
Total	0.512	-0.190	-0.023	0.603	0.457	0.586
-3,464	463.8	1838.2	1549.5	112.7	1099.7	694.4

Table 4. Efficiency in the Seller's Liability

	CD1	CD2	CBo1	CBo2	CBc1	CBc2
JPN	0.027	1.102	-0.419	0.800	0.995	0.475
	-371	0.0	10.0	10.0	10.2	-53.0
USA	-0.014	0.322	0.035	0.661	-0.355	0.833
	-3,162	20.4	0.0	-149.4	2.4	0.0
RU	0.828	0.349	1.413	0.947	0.967	0.922
	1,133	281.1	670.5	20.0	70.0	0.0
GER	-0.533	-0.396	-4.678	0.376	-6.913	1.564
	-234	53.0	54.8	269.0	55.1	586.0
FR	1.255	-1.805	-4.221	-1.683	-2.377	-66.520
	-59	5.0	86.0	121.0	66.0	35.1
UK	-6.276	0.619	-0.322	-10.414	1.870	1.424
	-151	301.4	20.0	99.5	669.0	0.0
RestEU	0.144	0.823	-0.072	-0.048	0.564	-0.423
	-350	0.0	5.0	8.9	0.0	15.0
EER	0.244	0.570	0.838	1.006	0.500	-0.370
	87	494.2	0.0	0.1	0.7	0.0
AU_NZ	-4.104	-0.406	-0.885	-0.536	-2.640	-2.789
	-149	125.7	0.0	1.0	0.0	81.0
CAN	-2.471	1.342	-3.265	0.767	0.973	0.935
	-208	218.0	0.6	22.0	19.5	93.9
Total	0.150	0.430	0.385	0.571	0.272	0.190
	-3,464	1498.8	836.9	402.1	892.7	821.2
						-905.2

Table 5. Efficiency in the Country-First Buyer's Liability

	KD1	KD2	KBo1	KBo2	KBc1	KBc2
JPN	-1.366	1.039	0.026	1.489	-2.688	0.703
	-371	320.0	121.0	61.8	33.5	-254.5
USA	-0.137	-0.036	1.816	1.779	-0.670	-0.146
	-3,162	-169.0	44.0	0.0	-195.0	178.2
RU	0.927	0.514	0.632	0.429	0.159	0.407
	1,133	178.6	118.0	794.7	0.0	1266.9
GER	-0.274	0.615	-0.571	1.817	-0.732	0.281
	-234	31.0	4.0	18.7	5.5	-36.0
FR	0.095	-1.842	-4.193	5.561	28.310	4.618
	-59	32.0	0.0	35.5	21.4	0.0
UK	-0.247	0.953	-6.754	-0.208	-4.155	0.653
	-151	45.0	5.0	53.9	-69.3	-79.8
RestEU	0.523	0.852	-10.459	-17.711	-0.956	-2.683
	-350	0.0	44.1	-317.0	-250.0	0.0
EER	0.753	0.312	-1.245	0.252	0.906	0.251
	87	77.7	157.8	390.7	0.0	0.0
AU_NZ	7.279	2.861	-10.372	-5.136	4.033	0.919
	-149	-3.3	0.8	33.6	80.0	0.0
CAN	-0.546	-0.997	-3.680	2.401	-4.161	-2.859
	-208	-8.0	71.0	275.2	66.7	147.3
Total	0.377	0.352	-0.147	0.196	-0.223	0.068
	-3,464	504.0	565.7	1347.1	-307.2	1222.1
						552.9

Table 6. Efficiency in the Kyoto-First Buyer's Liability