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Does the Varian Mechanism Work?
-- Emissions Trading as an Example

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Abstract

This paper investigates whether Varian's (1994) compensation mechanism can work in a laboratory. The results show that this mechanism does not work as in the theory. We found that the magnitude of penalties crucially affects subjects' behavior.

Key words: emissions trading; compensation mechanism; experiments

JEL classification: C91, D62, Q25

1. Introduction

How can we reduce emissions of greenhouse gases? It is one of the urgent issues in the world. However, there are some difficulties in solving this problem such as how to decide who reduces how much and how to design institutions that can implement the socially optimal allocation of emissions. The third session of the Conference of the Parties to the United Nations Framework Convention on Climate Change (UNFCCC) was held in Kyoto in 1997. It stipulated the target quota of greenhouse gases (GHGs) among the respective countries (Kyoto Protocol). In order to achieve this target, the Protocol decided to employ mechanisms such as emissions

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trading, joint implementation and the clean development mechanism. Before countries can begin emissions trading, however, rules must be negotiated and agreed on to ensure cooperation among all countries.

Emissions trading is one of the ways to minimize the cost of reducing GHGs. It has already been used to trade SO_2 and leaded gasoline in the US. Theoretically, if the market of emission permits is perfectly competitive, the allocation of GHGs in the market is efficient. That is, the cost of reducing the targeted GHGs is minimized regardless of the initial allocation of permits (Montgomery (1972)). A governmental agency does not need to know the cost functions of pollution sources. It needs only to decide the initial allocation of the emission permits and the market implements the efficient allocation automatically. However, there is no guarantee that the market is always perfectly competitive. If an agent who can supply many permits (such as Russia) and an agent who demands many of the permits (such as Japan) both enter the market, it is not guaranteed that the trading is made at a competitive equilibrium price. Depending on the initial allocation, they might lead the market to an inefficient allocation (Hahn (1984), Misiolek and Elder (1989)).

Contrary to this prediction, Varian (1994) described a class of compensation mechanisms whose subgame-perfect Nash equilibria implement socially efficient allocations in an environment in which there are only a few agents involved.

This paper examines whether this mechanism can work in a laboratory. Our design deals with the simplest case of only one demander and one supplier in the market. We found that few subjects chose the unique subgame-perfect Nash equilibrium. Many subjects coordinated implicitly toward a more profitable (but not socially optimal) outcome and some subjects chose Nash equilibria that were not subgame-perfect.

The paper is organized as follows. Section 2 presents the compensation mechanism. Section 3 describes the experimental design and procedures. Section 4 presents experimental results. Section 5 discusses the results. Section 6 offers conclusions.

2. The Compensation Mechanism in the Context of Emissions Trading

Consider a market involving two players who are assigned a certain amount of GHGs emissions to reduce. We assume their cost functions for reducing the emissions are increasing and strictly convex and call the assigned quota of emissions reduction w_i $(\mathrm{i}=1, 2)$. By introducing the following mechanism according to Varian (1994), the market can achieve the competitive equilibrium at its subgame-perfect Nash equilibrium even if only two players are involved. The mechanism consists of the following two stages:

Stage 1: Each player i simultaneously and independently offers a price for reducing emissions, $(p_i\ (\mathrm{i}=1, 2))$.

Stage 2: After observing p_2, player 1 chooses the amount of emissions reduction to trade with player 2 (denoted z hereafter). If the two announced prices in stage 1 are different, only player 1 has to pay a penalty to the regulator of this market.

The payoffs to player 1 and player 2 are given by

$$U_1 = -c_1(w_1 + z) + p_2 z - \alpha(p_1 - p_2)^2,\ \alpha > 0, \tag{1}$$

$$U_2 = -c_2(w_2 - z) - p_1 z. \tag{2}$$

The third term of the payoff function of player 1 is a penalty term. Although we chose the term to be a quadratic form with a positive number coefficient α for expositional purpose, it can be anything as long as the penalty is positive when the two prices are different and zero when they are the same. The payoff function of player 1 consists of the cost of reducing the amount of emissions after trading, the trade payment and any penalty, while the payoff function of player 2 consists of the cost of reducing the amount of emissions after trading and the trade payment.

To show that this mechanism can implement the efficient allocation at its unique subgame-perfect Nash equilibrium, we solve the problem of player 1 in the second stage first. The objective function of player 1 in the second stage is given by

$$\underset{z}{Max}\, U_1 = -c_1(w_1 + z) + p_2 z - \alpha(p_1 - p_2)^2. \tag{3}$$

Player 1 will choose z, which satisfies the following first–order condition:

$$c_1'\left(w_1 + z\right) = p_2. \tag{4}$$

This condition means that player 1 will decide z so that the marginal cost of reducing emissions is equal to the price determined by player 2 in the first stage. Since the cost function of player 1 is increasing and strictly convex, the following inverse function is derived from equation (4):

$$z = f(p_2). \tag{5}$$

Substitute (5) into (4) and differentiate it with respect to p_2. We obtain the following equation:

$$f'(p_2) = (c_1'')^{-1} > 0. \tag{6}$$

This equation means that as the price offered by player 2 increases, player 1 will reduce more emissions.

In the first stage, both players announce trading prices simultaneously and independently. For player 1, by differentiating her payoff function with respect to p_1, we obtain the following first-order condition:

$$p_1 = p_2. \tag{7}$$

This condition minimizes the penalty for player 1. On the other hand, since player 2 knows that p_2 affects z through the function $f(p_2)$, we obtain the following condition by differentiating the payoff function of player 2 with respect to p_2:

$$(c_2' - p_1) f'(p_2) = 0. \tag{8}$$

From equation (6), this condition is reduced to

$$c_2' = p_1. \tag{9}$$

We now check the second-order condition. We can obtain the second derivative by differentiating the left-hand-side of equation (8) with respect to p_2 as follows:

$$-c_2''\left[f'(p_2)\right]^2 + (c_2' - p_1) f''(p_2). \tag{10}$$

The first term of equation (10) is negative because of the curvature assumptions on the cost function of player 2; the second term becomes zero as a result of the condition given in equation (9). Therefore the second-order condition is locally satisfied. To satisfy the condition globally, however, minor restrictions have to be imposed on the marginal cost of player 2 and the second-order derivative of $f(p_2)$. From (4), (7) and (9), we find that this subgame-perfect Nash equilibrium satisfies the condition for efficiency. Although this is the unique subgame-perfect Nash equilibrium in this game, there exist many Nash equilibria, too. To be precise, a Nash equilibrium results when both players choose the same price (any price!) in the first stage, and player 1 chooses z to maximize her payoff given player 2's price.

3. Experiment Design and Procedures

3.1 Experimental Design

In the experiments, a profit maximizing individual tries to minimize her cost as much as possible. The cost functions of player 1 and player 2 are given by

$$c_1 = 37.5 + 0.5(\text{reduction amounts by player 1})^2,$$
$$c_2 = 0.75(\text{reduction amounts by player 2})^2.$$

These equations show that player 1 has fixed costs (=37.5) and a lower marginal cost, while player 2 does not have any fixed cost but has a higher marginal cost. From the social point of view, player 1 should reduce more emissions than player 2. Their payoff functions are given by

$$\pi_1 = -\left\{37.5 + 0.5(w_1 + z)^2\right\} + p_2 z - (penalty), \tag{11}$$

$$\pi_2 = -0.75(w_2 - z)^2 - p_1 z. \tag{12}$$

In the experiment, players were assigned initial amounts of emissions to reduce (w_1 =5 and w_2 =10). Each player simultaneously chooses a price $p_i \in \{0, 1, \cdots, 15\}$ in the first stage without knowing the price decided by the other player. In the second stage, only player 1 chooses a quantity $z \in \{-5, -4, \cdots, 10\}$ after observing the price decided by player 2. Although Varian's compensation mechanism does not specify the magnitude of the penalty or the form of it, different amounts of penalty or different forms of penalty could affect subjects' behaviors in different ways. Since we are interested in whether the magnitude of the penalty would change subjects' behaviors, we examined a low penalty case (*penalty*=10) and a high penalty case (*penalty*=50). To simplify the experimental design, we chose these lump-sum penalties instead of a quadratic form as in equation (1). Such modification does not change the original theoretical prediction. With the parameters mentioned above, the unique subgame-perfect Nash equilibrium is $\{p_1, p_2, z\} = \{9, 9, 4\}$.

3.2 Experimental Procedures

Two sessions were conducted using Osaka University undergraduates from various majors in 1997. In each session, twenty subjects (ten pairs) were seated in the same classroom. One session was run for the low penalty treatment, and the other was run for the high penalty treatment. Each subject participated in only one of the sessions. They were told before the experiment began that the experiment game would be repeated 20 periods. In our experiment, we did not use any words implying that we were concerned with environmental issues. In addition, we used the word "fee" in place of the word "penalty." Throughout the experiments, communication among subjects was not allowed. Subjects were told to play either role A (=player 1) or role B (=player 2) and we explained that they were to produce a certain amount of goods rather than tell them that they were trying to reduce emissions. To give them full information about payoffs, we explained and practiced both roles before they knew which role they were assigned. All the pairs of player 1 and player 2 were the same throughout the experiment, but they did not know who their partner was. The actual payment in the low penalty treatment was determined by

$$5{,}000 \text{ yen} + 2(\text{total payoff for 20 periods}). \tag{13}$$

The actual payment in the high penalty was determined by

$$6{,}000 \text{ yen} + 2(\text{total payoff for 20 periods}). \tag{14}$$

As explained in section 2 and shown in equations (11) and (12), payoffs of both players are negative since they consist mostly of costs for reducing emissions. Therefore we gave subjects seed money at the beginning of the experiment (5,000 yen in the low penalty treatment and 6,000 yen in the high penalty treatment (one US dollar=121yen)). Players could receive positive payments by trying to minimize the second term of the above equations (13) and (14). Not to give subjects the impression that one role was more advantageous than the other before the experiment began, we assigned the same payment formula to both player 1 and player 2.

4. Results

4.1 The Low Penalty Treatment

Table 1 presents the complete results of this treatment. Since the payoffs of both players are negative, we omit minus signs from the payoffs so that they indicate the total costs for reducing emissions including the trade payment. Figure 1 shows that the average total costs of both roles are lower than those in the subgame-perfect Nash equilibrium in most periods. This observation is confirmed by a t-test (a one tailed p-value<0.01). In addition, both of the average total costs decreased as the experiment proceeded, which is also statistically highly significant (a two tailed p-value<0.01). No pair chose the subgame-perfect Nash equilibrium throughout the session. Instead of the equilibrium, many pairs of subjects chose the outcome $\{p_1, p_2, z\} = \{0, 15, 10\}$ (60 outcomes of the 200 samples), where the total costs for both players were lowest, but not socially efficient. At this outcome player 1 has to pay the total cost of l0, but player 2 does not have to pay anything. Since the pairs were the same throughout the experiment, they cooperated with each other to minimize their total costs. Three pairs chose this outcome in the last period. One pair consistently chose a Nash equilibrium $\{p_1, p_2, z\} = \{8, 8, 3\}$ throughout the experiment. One pair maintained a Nash equilibrium $\{p_1, p_2, z\} = \{7, 7, 2\}$ from period 11 to period 19. However, player 2 of this pair changed her choice in the last period.

Figure 1. The Average Total Costs across Player 1s and across 2s in the Low Penalty Treatment

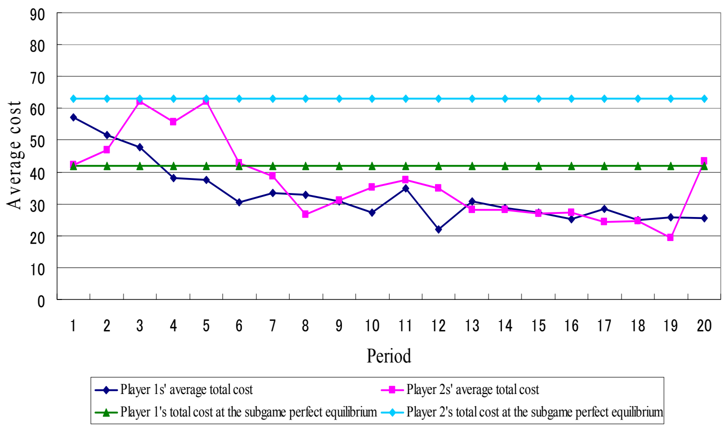


Table 1. Summary of Results in the Low Penalty Treatment: Prices and Quantities Announced by Players

	Period 1			Period 2			Period 3			Period 4			Period 5		
	p_1	p_2	z	p_1	p_2	z	p_1	p_2	z	p_1	p_2	z	p_1	p_2	z
Pair 1	3	6	2	7	5	2	7	7	2	8	15	10	0	6	0
Pair 2	3	7	2	4	5	0	2	8	0	1	6	-4	1	7	-5
Pair 3	8	8	3	8	8	3	8	8	3	8	8	3	8	8	3
Pair 4	2	0	2	0	15	0	10	15	10	2	15	10	15	15	10
Pair 5	7	8	3	7	7	4	7	6	4	7	2	2	7	14	4
Pair 6	1	15	10	4	14	9	13	15	10	0	15	10	1	15	9
Pair 7	0	5	10	0	10	10	0	10	10	0	10	5	0	10	5
Pair 8	0	10	5	0	10	10	0	10	10	0	15	10	0	15	10
Pair 9	5	8	3	3	11	6	2	6	1	4	5	0	3	13	8
Pair 10	8	7	2	13	7	2	7	5	0	14	10	6	7	6	2

	Period 6			Period 7			Period 8			Period 9			Period 10		
	p 1	p 2	z	p 1	p 2	z	p 1	p 2	z	p 1	p 2	z	p 1	p 2	z
Pair 1	0	5	0	0	7	2	0	15	10	0	15	10	0	15	10
Pair 2	2	10	6	0	11	6	0	12	7	0	13	8	0	15	10
Pair 3	8	8	3	8	8	3	8	8	3	8	8	3	8	8	3
Pair 4	15	15	10	15	15	10	15	0	-5	15	0	-5	0	0	-5
Pair 5	7	9	4	7	0	4	7	0	4	7	0	4	7	0	2
Pair 6	0	15	10	0	15	10	0	15	8	1	15	10	0	15	10
Pair 7	0	15	10	0	15	10	0	15	10	0	15	10	0	15	10
Pair 8	0	15	10	0	15	10	0	15	10	0	15	10	0	15	10
Pair 9	1	14	9	0	15	10	0	15	10	1	15	10	0	15	10
Pair 10	2	6	2	7	6	2	0	6	2	6	6	1	6	7	2

	Period 11			Period 12			Period 13			Period 14			Period 15		
	p_1	p_2	z	p_1	p_2	z	p_1	p_2	z	p_1	p_2	z	p_1	p_2	z
Pair 1	0	15	10	0	15	10	0	15	10	0	15	10	0	15	10
Pair 2	1	15	10	1	14	9	0	15	10	1	15	10	1	15	10
Pair 3	8	8	3	8	8	3	8	8	3	8	8	3	8	8	3
Pair 4	0	15	-5	15	15	10	0	5	0	3	5	0	5	5	0
Pair 5	7	0	2	7	10	4	7	2	2	7	0	2	7	1	2
Pair 6	0	15	8	1	15	10	0	15	6	0	15	9	0	15	10
Pair 7	0	15	10	0	15	10	0	15	10	0	15	10	0	15	10
Pair 8	0	15	10	0	15	10	0	15	10	0	15	10	0	15	10
Pair 9	1	15	10	0	14	9	1	13	8	1	15	10	0	15	10
Pair 10	7	7	2	7	7	2	7	7	2	7	7	2	7	7	2

	Period 16			Period 17			Period 18			Period 19			Period 20		
	p_1	p_2	z	p_1	p_2	z	p_1	p_2	z	p_1	p_2	z	p_1	p_2	z
Pair 1	0	15	10	0	15	10	0	15	10	0	15	10	0	15	10
Pair 2	1	14	9	0	15	10	1	15	10	1	15	10	1	15	10
Pair 3	8	8	3	8	8	3	8	8	3	8	8	3	8	8	3
Pair 4	5	6	1	5	7	2	5	9	4	5	9	4	9	10	5
Pair 5	7	13	7	7	0	2	7	11	6	0	10	8	0	10	8
Pair 6	1	15	9	0	15	10	0	15	8	0	15	10	0	5	0
Pair 7	0	15	10	0	15	10	0	15	10	0	15	10	0	15	10
Pair 8	0	15	10	0	15	10	0	15	10	0	15	10	15	15	10
Pair 9	1	15	10	0	15	10	1	15	10	1	15	10	0	15	10
Pair 10	7	7	2	7	7	2	7	7	2	7	7	2	7	15	10

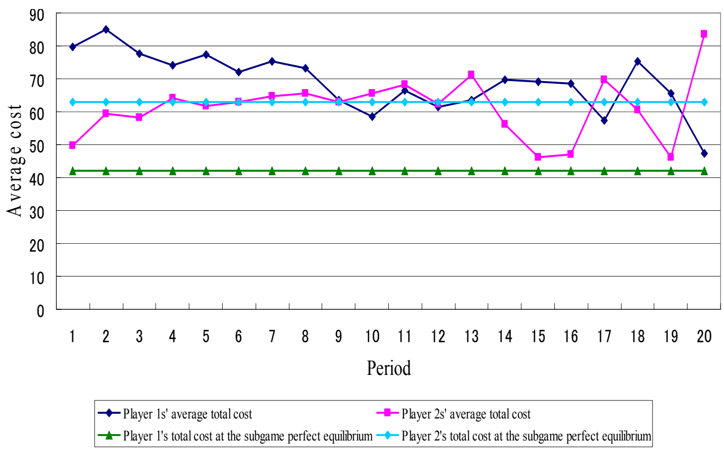
Table 2. Summary of Results in the High Penalty Treatment: Prices and Quantities Announced by Players

		Period 1			Period 2			Period 3			Period 4			Period 5		
		p_1	p_2	z	p_1	p_2	z	p_1	p_2	z	p_1	p_2	z	p_1	p_2	z
Pair	1	5	9	4	3	7	2	6	10	6	8	7	2	12	8	3
Pair	2	9	9	4	9	9	4	9	5	0	5	12	7	8	3	-2
Pair	3	0	12	7	0	12	10	0	12	7	0	13	9	0	15	10
Pair	4	8	9	4	9	10	4	8	9	4	9	8	4	9	8	4
Pair	5	0	11	6	5	8	3	2	7	2	15	11	6	0	6	1
Pair	6	6	5	6	9	4	3	6	10	6	7	0	-5	8	15	10
Pair	7	11	8	4	13	9	4	8	7	2	8	15	10	12	3	-2
Pair	8	10	15	10	6	15	0	5	15	10	0	15	10	0	15	10
Pair	9	2	15	10	7	15	10	15	15	10	15	14	9	14	13	8
Pair	10	10	6	1	13	7	2	2	10	5	2	12	7	6	13	8
		Period 6			Period 7			Period 8			Period 9			Period 10		
		p_1	p_2	z	p_1	p_2	z	p_1	p_2	z	p_1	p_2	z	p_1	p_2	z
Pair	1	10	8	3	7	8	3	8	8	3	8	8	3	8	8	3
Pair	2	15	0	-2	15	15	6	7	15	6	7	15	10	6	15	10
Pair	3	0	15	10	0	15	10	0	15	10	0	15	10	0	15	10
Pair	4	9	8	3	8	7	3	8	7	3	8	7	3	7	7	2
Pair	5	0	9	4	3	15	10	11	15	10	13	15	10	15	14	9
Pair	6	3	10	6	13	10	4	10	5	0	5	5	2	5	14	9
Pair	7	7	5	0	6	1	-4	14	6	1	5	14	9	7	10	5
Pair	8	15	15	10	15	5	0	5	15	10	0	15	10	0	15	10
Pair	9	12	12	7	11	8	3	4	5	0	8	0	-5	0	0	-5
Pair	10	6	11	6	6	12	7	14	11	6	12	9	4	11	7	2
		Period 11			Period 12			Period 13			Period 14			Period 15		
		p_1	p_2	z	p_1	p_2	z	p_1	p_2	z	p_1	p_2	z	p_1	p_2	z
Pair	1	8	8	3	8	8	3	8	8	3	8	8	3	8	8	3
Pair	2	13	15	8	7	15	10	15	15	9	15	13	8	11	5	0
Pair	3	0	15	10	0	15	10	0	15	10	0	15	10	0	15	10
Pair	4	7	8	3	8	8	3	8	7	2	8	7	2	8	7	2
Pair	5	15	8	3	9	10	5	7	7	2	12	9	4	11	7	2
Pair	6	7	2	-2	5	7	4	4	3	-2	11	4	-4	7	14	9
Pair	7	8	11	6	8	13	8	14	12	7	9	9	4	9	9	4
Pair	8	15	15	10	0	6	2	0	15	10	0	15	10	0	15	10
Pair	9	0	15	10	15	15	10	15	0	-5	0	15	10	0	15	10
Pair	10	12	7	2	7	13	8	13	11	6	13	7	2	4	6	1
		Period 16			Period 17			Period 18			Period 19			Period 20		
		p_1	p_2	z	p_1	p_2	z	p_1	p_2	z	p_1	p_2	z	p_1	p_2	z
Pair	1	8	8	3	8	8	3	8	8	3	8	8	3	8	8	3
Pair	2	0	0	-4	15	15	7	12	15	10	15	5	0	0	9	4
Pair	3	0	15	10	0	15	10	0	15	10	0	15	10	5	15	10
Pair	4	8	7	2	9	7	-5	8	7	3	7	7	5	7	7	5
Pair	5	7	6	1	15	10	5	15	9	4	14	11	6	9	9	4
Pair	6	2	10	4	10	15	6	10	3	-2	10	14	8	10	15	7
Pair	7	9	6	1	4	8	3	6	5	0	6	7	2	9	10	5
Pair	8	0	15	10	0	15	10	0	15	10	0	15	10	15	15	10
Pair	9	0	15	10	15	15	10	0	15	0	0	15	10	15	15	10
Pair	10	3	13	8	4	14	9	5	13	8	4	13	8	14	15	10

4.2 The High Penalty Treatment

Table 2 presents the complete results of this session. Figure 2 shows that the average total cost among player 1s is higher than the total cost in the subgame-perfect Nash equilibrium. This observation is confirmed by a t-test (a one tailed p-value<0.01). On the other hand, the average total cost among player 2s is not much different from the total cost in the subgame-perfect Nash equilibrium, which is confirmed statistically (a two tailed p-value of 0.549). In addition to that, we found that player 1s' average total cost decreased significantly period by period (a two tailed p-value < 0.01), while player 2s' average total cost did not decrease significantly period by period (a two tailed p-value of 0.777). The subgame-perfect Nash equilibrium was chosen five times and one pair chose the equilibrium in the last period. The frequency of the outcome $\{p_1, p_2, z\} = \{0, 15, 10\}$ is less than that in the low penalty treatment (31 outcomes of the 200 samples). However, this outcome was still the most frequent throughout the session. Although two pairs seemed to converge toward $\{p_1, p_2, z\} = \{0, 15, 10\}$, where the total cost for player 1 is 50 and the total cost for player 2 is 0, no pair chose this outcome in the last period. The player 1 of one of those pairs chose $p_1 = 15$ for several periods to make her penalty zero. One pair consistently chose a Nash equilibrium $\{p_1, p_2, z\} = \{8, 8, 3\}$ from period 8 till the last period.

Figure 2. The Average Total Costs across Player 1s and across 2s in the High Penalty Treatment



4.3 Comparison between two Penalty Treatments

There are three types of behaviors. The first type is reciprocal behavior: Player 1 chooses the lowest price for player 2 to make player 2's cost zero and player 2 chooses the highest price for player 1 so that player 1 can minimize the cost by choosing the optimal z (but player 1 has to pay the penalty). The second type is Nash behavior: player 1 chooses the same price as p_2 to minimize the penalty and choose an optimal z given a p_2. The third type is other-regarding behavior: some player 1s did not choose the optimal z under a certain p_2. In the low penalty treatment, we observed many of the first type of behavior. In the high penalty treatment, this behavior decreased. Although the number of pairs who chose the subgame-perfect Nash equilibrium increased in the high penalty treatment, such pairs were few. Instead of the subgame-perfect Nash equilibrium, some pairs chose Nash equilibria. There are sixteeen Nash equilibria in this experimental mechanism. In the low penalty treatment, no subgame-perfect Nash equilibrium was chosen, but other Nash equilibria were chosen thirty-eight times in total. $\{p_1, p_2, z\} = \{0, 0, -5\}$ was chosen once, $\{p_1, p_2, z\} = \{5, 5, 0\}$ was chosen once, $\{p_1, p_2, z\} = \{6, 6, 1\}$ was chosen once, $\{p_1, p_2, z\} = \{7, 7, 2\}$ was chosen ten times (nine times were chosen by the same pair), $\{p_1, p_2, z\} = \{8, 8, 3\}$ was chosen twenty times (by the same pair) and $\{p_1, p_2, z\} = \{15, 15, 10\}$ was chosen five times. In the high penalty treatment, the subgame-perfect Nash equilibrium was chosen five times. Other Nash equilibria were chosen twenty-five times in total. $\{p_1, p_2, z\} = \{0, 0, -5\}$ was chosen once, $\{p_1, p_2, z\} = \{7, 7, 2\}$ was chosen twice, $\{p_1, p_2, z\} = \{8, 8, 3\}$ was chosen fourteen times (thirteen times were chosen by the same pair), $\{p_1, p_2, z\} = \{12, 12, 7\}$ was chosen once and $\{p_1, p_2, z\} = \{15, 15, 10\}$ was chosen seven times. Although in the high penalty treatment the rate of pairs who chose the subgame-perfect Nash equilibrium increased, the total number of Nash outcomes (even including the subgame-perfect Nash equilibrium) was less than in the low penalty treatment.

As was mentioned above, there were player 1s who did not choose an optimal z given a p_2 in the second stage both in the low penalty and high penalty treatments. The rate of best response by player 1 in the low penalty was 79% and 82% in the high penalty treatment throughout each session. In our experiment parameters, player 1's optimal choice of z is decided by the following equation:

$$z^* = -5 + p_2.$$

We ran a simple linear regression of player 1's quantity choice (z) on a single predictor variable player 2's price (p_2). The regression results show that the coefficient on p_2 of the low penalty treatment was 0.75 (a two tailed p-value<0.01) and that of the high penalty treatment was 0.91 (a two tailed p-value<0.01). That is, the higher penalty induced more rational behavior by player 1s.

4.4 Efficiency Comparison

In the compensation mechanism, the budget is not balanced off the equilibrium path. When p_1 does not equal p_2, the regulator of this market has to compensate for the difference between the paid amount of money and the received amount of money, or she can benefit from the price difference. Therefore her payoff function can be expressed by

$$\pi_R = p_1 z - p_2 z + penalty \qquad \text{if } p_1 \neq p_2 \text{ and } z \geq 0,$$

$\pi_R = (-p_2 z) + p_1 z + penalty$ if $p_1 \neq p_2$ and $z < 0$,

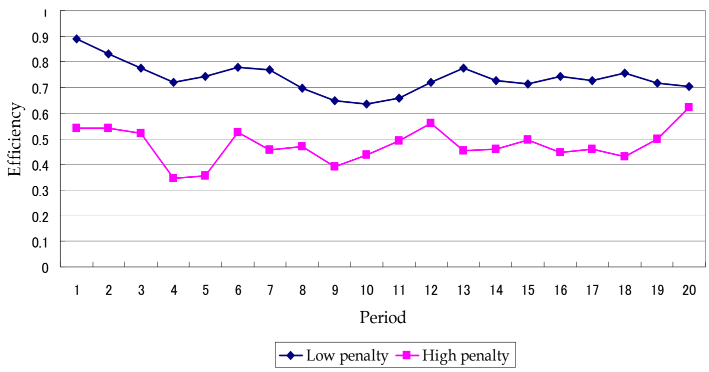
$\pi_R = 0$ if $p_1 = p_2$.

The social surplus of one transaction consists of player 1's payoff (π_1), player 2's payoff (π_2) and the regulator's payoff (π_R). The sum of these payoffs is negative because they are mostly costs for reducing the target amount of emissions. Therefore we express the social total cost as $STC = -(\pi_1 + \pi_2 + \pi_R)$ and define efficiency of one transaction by the following formula:

$$Efficiency = \frac{105 - (STC - 105)}{105}.$$

105 is the minimum and most efficient social total cost at the subgame-perfect Nash equilibrium (π_1 = -42, π_2 =-63 and π_R =0). When the social total cost is 105, efficiency equals 1. However, there are cases other than the subgame-perfect Nash equilibrium whose social total cost is 105. Figure 3 compares the average efficiency period by period in the low penalty treatment and the high penalty treatment. It shows that the efficiency in the low penalty is higher than in the high penalty treatment across all the periods. To confirm this observation, we tested whether efficiency in the low penalty treatment is significantly higher than that in the high penalty treatment using a paired t test and found that this observation was true (a one tailed p-value<0.01). That is, a higher penalty does not necessarily lead to a more efficient result.

Figure 3. Efficiency Comparison between the Low Penalty Treatment and the High Penalty Treatment



5. Discussion

From the experiment results, we found that there are several aspects in the compensation mechanism that make subjects deviate from the theoretical prediction. One aspect is that there are many Nash equilibria other than the subgame-perfect Nash equilibrium. Among all the Nash equilibria, the most preferable outcome for player 1 is $\{p_1, p_2, z\} = \{15, 15, 10\}$, while the most preferable outcome for player

2 is $\{p_1, p_2, z\} = \{8,\ 8,\ 3\}$. Therefore the subgame-perfect Nash equilibrium was not a focal point. As was mentioned in section 4.3, $\{p_1, p_2, z\} = \{8,\ 8,\ 3\}$ was the most observed Nash equilibrium among all the Nash equilbria. This might be because a price choice of 8 is the most preferable for player 2. Therefore, player 1 had to choose the same price to minimize her penalty. In addition to that, since the payoff functions of both players are relatively flat near the subgame-perfect Nash equilibrium, a small deviation from the equilibrium was not so costly to player 1. The other aspect is the influence of penalties. Theoretically, the form of the penalty can be anything and the magnitude of the penalty does not matter. However, we observed a significant difference between the low penalty treatment and the high penalty treatment.

6. Conclusion

In our experiments, we could not create an environment in which the compensation mechanism can work. In spite of the absence of communication, subjects cooperated implicitly and chose a more profitable outcome for them than in the subgame-perfect Nash equilibrium. One of the aspects in this mechanism is that there are many Nash equilibria. That might prevent subjects from focusing on the subgame-perfect Nash equilibrium. We examined two kinds of penalty treatments and found that raising the magnitude of the penalty is not sufficient to induce subjects to choose the subgame-perfect Nash equilibrium. Theoretically the form and the magnitude of the penalty do not matter in determining the socially optimal outcome. However, we found that penalties control subjects' behaviors significantly. To make this mechanism work as in the theory, it is necessary to consider and test experimentally what form and magnitude of penalty can actually lead to the socially preferable outcome. Our study is concerned with the case where only player 1 pays a penalty. To examine the case where player 2 also has a penalty, and whether the same theoretical prediction of Varian's original model holds, shall be left to future research.

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