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Efficiency of Individual Transferable Quotas (ITQs) when Fishers are able to Choose Vessel Sizes: An experimental approach[‡]

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Abstract

Employing an experimental approach, this paper examines whether the efficiency of fishery management can be achieved under Individual Transferable Quotas regimes. We analyze the situation in which subjects can choose from one of two vessel types: large-scale or small-scale. The fixed cost for large-scale vessels is higher than that for their small-scale counterparts, whereas the variable cost for large-scale vessels is lower. We find that the average trading price (ATP) converges to the theoretical equilibrium price (EQP). We also find that vessels are chosen rationally in the sense that, the greater the ATP, minus the EQP in past periods, the less incentive subjects have to invest in large-scale vessels. Moreover, quota prices in the first period could influence both the quota prices and the numbers of both types of vessels in the ensuing periods, and initial allocation could affect the rational choice of vessels.

Key Words: Individual Transferable Quotas, tradable permits, experiment, double auction.

JEL Classification: C91, Q22, Q28.

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1. Introduction

Marine resources have been seriously depleted in the past few decades, and some of them are in danger of exhaustion. According to the Food and Agriculture Organization of the United Nations (FAO, 2008), more than 70 percent of marine stocks assessed are fully exploited or overexploited as of 2006.

In response to this problem, governments and communities have implemented policies and schemes for management of their fisheries. Like other environmental and resource problems, the introduction of market mechanisms, called Individual Transferable Quotas (**ITQ**s), are considered effective to tackle this problem. Under this regime, the authority determines the Total Allowable Catch (**TAC**) and the initial allocation of fishing rights/quotas. Fishers are able to transact those fishing rights/quotas in the quota market. This regime has been introduced in several countries, such as New Zealand, Iceland, and Australia since the 1980s.[1] Under an ITQ regime, an inefficient fisher gains more from selling quotas that s/he holds to other efficient fishers than from harvesting by herself/himself. Thus, fishers do not compete with each other for catching more fish with higher speed. When an ITQ regime is established with TAC, it is considered that the efficiency of fishing activities and the proper resource management are achieved simultaneously.

On the other hand, some defects of ITQs have been pointed out, both theoretically and empirically. Newell et al. (2005) found that quota prices could be unstable for the first several periods, in particular, after the introduction of an ITQ system in New Zealand. The possible reason is that it takes a long time for fishers to get used to quota trading systems and to find the equilibrium price. Another possible reason is speculation. Fishers may expect that they will be able to resell quotas later at a higher price.[2]

Experimental approaches are particularly effective to extract the functions of market

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[1] For empirical case studies, see, for example, Clark et al. (1988), Eythorsson (2000), Gauvin et al. (1994), and Weinger (1998).

[2] There are other theoretical analyses on the defects of ITQs. Vestergaard (2005) demonstrated that the existence of sunk costs delays the achievement of the optimal fleet structure. Bergland and Pederson (2006) considered the case in which some fishers are risk averse, and proved that they buy fewer quotas than those who are risk neutral. Moreover, Anderson (1991) demonstrated that, to harvest a certain amount of fish when some fishers have market power in the quota market, total cost is not minimized.

mechanisms and the behavior of stakeholders on the markets of tradable permits. Many experimental studies have verified that possible flaws of tradable permits could take place in the real world, such as price instability, noncompliance behavior, and distortions due to market power. For example, emissions trading has been drawing much attention (see Cason et al. (2003), Cason and Gangadharan (2006), Gangadharan et al. (2005), Godby (1997), Godby (2000), Ledyard and Szakaly-Moore (1994), Murphy and Stranlund (2007)).

The efficiency of ITQ regimes can also be analyzed by using experiments. For example, the possibility that quota prices are unstable has been clarified. Anderson (2004) and Anderson and Sutinen (2005) provided the basic experiments for ITQ schemes, and found that quota prices may be much higher than those in equilibrium in which efficiency is achieved. Anderson and Sutinen (2006) demonstrated that the introduction of initial lease periods mitigates the problem of instability of quota prices. In other words, the possibility that a quota price increases due to speculation becomes weaker. This is because fishers do not consider quotas as assets in the lease periods, and find the equilibrium price during those periods. Moreover, Anderson et al. (2008) examined the relationship between cost structures and the situations of quota markets.

Little attention, however, has been given to changes in scales of vessels. In reality, many inefficient fishers keep engaging in fishing activities. In some cases, there are too many small-scale fishers, which implies that a situation of excess entry takes place. In other cases, sizes of existing vessels are too large, implying excess investment by each fisher. For example, Managi (2009) estimated the inefficiency in the Japanese fishing industry and indicated the possibilities of cost reductions.

Because each fisher can choose the scale of her/his own fishing vessel, the introduction of an ITQ regime may make fishers change their vessel scales. As noted above, since an inefficient fisher gains more from selling quotas that s/he holds to other efficient fishers than from harvesting by herself/himself, it is natural that each fisher has less incentive to keep/buy an inefficient vessel when an ITQ regime exists than when there is no such regime. Thus, it is considered that the introduction of ITQs makes vessel scales more efficient. Arnason (1993) and Geen and Nayar (1988) evaluated the introduction of ITQs in terms of the efficiency of vessel scales for the cases of Iceland and Australia, respectively.

Using the experimental approach, this paper examines (a) whether or not vessel scales are rationally chosen; and (b) whether or not ITQ markets function well. The first of our findings is that the average trading price (**ATP**) converges to the theoretical equilibrium price (**EQP**) given numbers of both types of vessels, although it may take a long time. Second, each fisher/subject chooses the scale of vessel rationally in the sense that, the greater is the ATP minus the EQP in the past periods, the less likely it is that s/he chooses a large-scale vessel. This implies that, when the quota market cannot realize the efficient equilibrium price, it is likely that the combination of efficient vessel scales cannot be realized. Moreover, we find that the quota price in the initial period and the initial allocation of quotas could play important roles in realizing an efficient situation.

The structure of the paper is as follows. Section 2 describes the theoretical background. Section 3 refers to the experimental design. Section 4 examines the results of basic experiments, in which quotas are allocated equally in the beginning. Section 5 refers to additional experiments in which quotas (initial allocation) are not allocated to fishers/subjects equally. Section 6 provides concluding remarks.

2. Theoretical Specification

Consider a fishery with N fishers. Each fisher engages in fishing with one vessel that is large- or small-scale (types L or S, respectively). Each fisher harvests fish stock of a single species. All vessels of a given type are identical. Moreover, in terms of fishing technique, all fishers are identical, which implies that their cost conditions are equal to each other if they have the same type of vessels.

The cost structure of each type of vessel is:

$$C_i(q_i) = c_i(q_i) + F_i,\ c_i' > 0, \quad c_i'' > 0, \tag{1}$$

where q_i, c_i, and F_i denote the amount of catch, the variable cost, and the fixed cost of type $i(i = L, S)$, respectively. It is assumed that $F_L > F_S$, and $c_L' < c_S'$ for any given amount of catch. Moreover, since we assume the existence of fixed costs and increasing marginal costs, there exists a unique amount of catch that minimizes the average cost (AC) for each type, $\hat{q}_i\left(i = L, S\right)$. We assume that a large-scale vessel is more efficient than a small-scale fisher, in the sense that:

$$AC_L\left(\hat{q}_L\right) < AC_S\left(\hat{q}_S\right), \qquad \hat{q}_L > \hat{q}_S. \tag{2}$$

Figure 1 shows both types of cost structures.[3]

The government sets TAC, denoted by $\overline{Q}$, determines the initial allocation to each fisher, and introduces an ITQ program for the fishery. The amount of $\overline{Q}$ and the initial allocation are constants for fishers. The demand curve for fish is downward sloping:

$$p = P\left(\overline{Q}\right), \; P' < 0. \tag{3}$$

Unless the government changes the TAC level, the price of fish does not change.

We consider a two-step determination of the harvesting structure. In the first stage, given the initial allocation, each fisher chooses the type of vessel s/he uses, and quotas are transacted between fishers in the second stage. We do not consider the case in which a fisher chooses to quit fishing by selling all the quotas s/he holds. It is considered that both new entry and exit do not take place because of the initial costs for entry and the costs of switching to other industries. Thus, a seller sells only a part of the quotas s/he holds. Quotas are transacted in a perfectly competitive market, which also means that both types of fishers are price takers in the quota market. The notion of equilibrium is a Sub-game Perfect Equilibrium, and we consider the determination of the harvesting structure by backward induction.

We assume that large-scale fishers are buyers of quotas, while small-scale fishers are sellers of them. In other words, the initial allocation is determined so that large-scale (small-scale) fishers buy (sell) quotas in the second stage.[4] Moreover, we exclude the case in which a fisher does not use part of her/his quotas to manipulate the quota price.

In the second stage, each type of fisher determines the amount of catch, and, accordingly,

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[3] In reality, larger vessels might be less efficient. However, the assumption that larger vessels are more efficient does not matter for our purpose. Both in theory and experiments, the opposite case can be analyzed in a similar way.

[4] The opposite case can be analyzed theoretically in a similar way and similar results are obtained. Moreover, experiments for both cases can easily be conducted. For the present focus, and for simplicity, we deal with the case described in the text.

the amount of quotas that s/he buys (or sells) so that her/his profit is maximized given the price of quotas. The profit function of fisher j when her/his vessel type is i is given by:

$$\pi_{i,j} = p(\overline{Q})q_{i,j} - C_i(q_{i,j}) - r \cdot (q_{i,j} - \overline{q}_j), \qquad i = L, S, \tag{4}$$

where r and $\overline{q}_j$ denote the price of quota and the initial allocation for fisher j, respectively. The first-order condition (FOC) is:

$$p(\overline{Q}) - c_i' - r = 0. \tag{5}$$

Let q_L^T (q_S^T) denote the amount of catch of each large-scale (small-scale) fisher in equilibrium. Then, the following conditions hold given the number of each type of fisher:

$$c_L'(q_L^T) = c_S'(q_S^T), \tag{6}$$

$$n_L q_L^T + (N - n_L) \cdot q_S^T = \overline{Q}. \tag{7}$$

Thus, the equilibrium outputs and the quota price can be represented as $q_i^T(n_L, \overline{Q})$ $(i = L, S)$ and $r(n_L, \overline{Q})$, respectively. It is noted that the amounts of catches are not influenced by the initial allocations as far as the numbers of both types of vessels are given.

From (6) and the assumption that $c_L' < c_S'$ for any given amount of catch, it is clear that the amount of catch of a large-scale fisher is greater than that of a small-scale fisher for any given quota price. This implies that, the greater is the number of large-scale fishers, the greater is the total demand for quotas.[5] Since the TAC is fixed, the following remark is established.[6]

Hypothesis 1: *The equilibrium quota price is influenced by the numbers of both types of vessels. In particular, the larger is the number of large-scale vessels, the higher is the quota price in the second-stage equilibrium.*

In the first stage, each fisher chooses her/his vessel type so that her/his profit is maximized. Although their profits depend on the numbers of both types of vessels and the TAC level, we

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[5] The greater is the number of large-scale fishers, the smaller is the number of small-scale fishers, since the total number, N, is fixed.

[6] See Appendix A for the continuous case.

simply represent them as $\Pi_i\left(n_L\right)(i = L, S)$ because the total number of fishers and the TAC level are fixed. Then, when the following two conditions are satisfied, n_L^* and $n_S^* (= N - n_L^*)$ are equilibrium vessel numbers in the sense that no one has an incentive to change her/his own vessel type:

$$\Pi_L\left(n_L^* + 1\right) < \Pi_S\left(n_L^*\right), \quad \Pi_S\left(n_L^* - 1\right) < \Pi_L\left(n_L^*\right). \tag{8}$$

As shown in Anderson and Sutinen (2005) and Newell et al. (2005), however, quota prices are not necessarily determined based on (6) and (7). This means that the quota price in the second stage is uncertain at the starting point of the first period from the viewpoint of each fisher. In such a case, in the first stage, it is likely that each fisher chooses her/his own vessel type based on her/his expected quota price in the second stage ($\tilde{r}$). Let α denote the factor that positively affects the expected quota price. For example, the quota prices in the past periods are likely to influence the expected quota price positively. Then, the expected quota price is given by:

$$\tilde{r}\left(n_L, \alpha\right), \quad \partial\tilde{r}/\partial\alpha > 0. \tag{9}$$

In this case, in the first stage, fisher j chooses a vessel to maximize her/his own expected profit ($\tilde{\Pi}_{i,j}$), which can be written as:

$$\tilde{\Pi}_{i,j}\left(n_L\right) = p\left(\overline{Q}\right)q_i\left(\tilde{r}\left(n_L, \alpha\right)\right) - C_i\left(q_i\left(\tilde{r}\left(n_L, \alpha\right)\right)\right) - \tilde{r}\left(n_L, \alpha\right) \cdot \left(q_i\left(\tilde{r}\left(n_L, \alpha\right)\right) - \overline{q}_j\right), \quad i = L, S. \tag{10}$$

Each fisher also expects the FOC as follows:

$$p\left(\overline{Q}\right) - c_i' - \tilde{r} = 0. \tag*{(5)'}$$

It is assumed that large-scale (small-scale) fishers are buyers (sellers) of quotas. Therefore, from (5)', the effects of a change in α on the expected profits for any given numbers of both types of vessels are given by:

$$\frac{d\tilde{\Pi}_{L,j}}{d\alpha} = -\frac{\partial\tilde{r}}{\partial\alpha} \cdot \left(q_L - \overline{q}_j\right) < 0, \quad \frac{d\tilde{\Pi}_{S,k}}{d\alpha} = -\frac{\partial\tilde{r}}{\partial\alpha} \cdot \left(q_S - \overline{q}_k\right) > 0, \tag{11}$$

where j and k are indexes for fishers. This implies that, the greater is the expected quota price minus the theoretical equilibrium price without any bias by α, the less incentive fishers have to invest in large-scale vessels for any given numbers of both types of vessels. The intuition is as follows. The higher is the expected quota price ($\tilde{r}$), the less (more) profit a fishers gains if s/he becomes a seller (a buyer) of quotas in the second stage. Thus, fishers have more incentive to have small-scale vessels and to be sellers of quotas. Consequently, the following remark is established.

Hypothesis 2: *As the expected quota price of fishers as compared with the theoretical equilibrium price (EQP) becomes higher, it is likely that the number of small-scale fishers becomes greater.*

3. Experimental Design: Basic Sessions

3.1 Sessions

We conduct eight basic sessions, in each of which 12 subjects trade quotas in a computerized double auction. The ages of subjects are under 30, and they were mainly undergraduate and vocational school students. They participated in one session only and were paid an average of \$30, based on an exchange rate of 100 Japanese yen = 1 US dollar. In the beginning of each session, subjects read the instructions for about 10 minutes.[7] In this experiment, each session includes 10 periods and each period is divided into two stages.

At the beginning of each period, each subject is given an "initial allocation." In the first stage, each subject chooses between a large (more efficient) and a small (less efficient) fishing vessel. In the second stage, each subject can adjust their quota holdings by buying or/and selling quotas in the double auction scheme. To familiarize subjects with the experiments, we ran two training periods before conducting paying periods.

We use the technical terms specific to fisheries to describe the experimental design and results in this paper. However, terminology that is more neutral was used with the subjects. For example, we referred to a fish quota as a "coupon" and marginal cost as marginal "production cost." After the experiment, subjects answered a questionnaire that was used to measure their

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[7] The instruction manual is available upon request.

risk preferences.[8] We conducted the experiment using the University of Zurich's Z-tree program (Fischbacher, 1999).[9]

3.2 Investment decision stage

In the first stage, each subject chose a way of production between Type 1 (small-scale) and Type 2 (large-scale), which we call "investment" hereafter. The fixed cost of Type 1 was smaller than that of Type 2, whereas the marginal/variable cost of Type 1 was higher than that of Type 2 (see Figure 1). In this experiment, the fish price was fixed, and it was equal to 30. In other words, the revenue from selling one unit of fish was always 30. At the beginning of each period, each subject was given eight quotas/coupons as the initial allocation, which implies that TAC was 96. S/he was also given a sheet in which fixed costs and marginal costs of both types were written (see Table 1 for the cost structures). According to the cost structures of both types, five subjects would choose Type 1 and seven subjects would choose Type 2 in Nash equilibrium. In the present setting of the cost structures, TAC, and the price of fish, this is also the most efficient situation if we consider only integers for vessel numbers. This implies that the total cost of producing 96 units is minimized.[10] In each period, each subject could observe the investment result, which was the numbers of both types of vessels, on her/his own display from the end of the first stage through the second stage.[11]

3.3 Quota trading stage

In the second stage, each subject can adjust their quota holdings by buying or/and selling quotas/coupons in the double auction scheme. It is considered that a rational fisher maximizes her/his own profit. Similarly, in the controlled experiment, subjects buy/sell quotas to

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[8] See Appendix B for the details on the questionnaire. An analysis on risk attitude is not the main purpose of this paper. We, however, conduct this questionnaire to exclude risk factors.

[9] These sessions were conducted at the Yokohama National University in September 2009 and January 2010. Each session lasted about one and a half hours.

[10] In general, the combination of numbers of vessels of both types in Nash equilibrium is different from that in the social optimum. In the present setting, this is also true if we consider the determination of the numbers of both types of vessels continuously. However, we allow only integers for vessel numbers in this paper.

[11] Each subject could not identify who chooses which type of vessel. They could see only the numbers of vessels in the period.

maximize their own profits, which are determined by (a) how many quotas s/he holds after trading; and (b) how many quotas s/he buys/sells. When the initially allocated amounts of quotas are equal to eight for all subjects, it is clear that Type 1 (Type 2) sells (buys) quotas in the second stage. In the present setting of cost structures of both types, if the most efficient situation was realized in the first stage, Type 1 would sell five or six quotas/coupons, Type 2 would buy three or four quotas/coupons, the price of quota/coupon would be 11, and the profit for each subject would be equal to 74.

A deal was made whenever a buyer (a seller) accepted the current bid (the current ask). After each trade, the current bid and ask were closed and the market opened for a new set of bid and ask. The history of trading prices was displayed on the screen. The quota market was open for the entire period, each of which lasted three minutes.

4. Results of Basic Sessions

4.1 Theoretical equilibrium prices (EQPs)

Since subjects were able to choose types of vessels in each period, the EQP depended on the combination of numbers of both types of vessels. The list of EQPs is shown in Table 2. Some of them are not integers, since there is more than one possible equilibrium price.

4.2 Description of prices and numbers of vessels

The summary of results is shown in Tables 3 and 4, and Figures 2 and 3. As noted in the previous section, the number of Type 1 (small-scale) is five and the number of Type 2 (large-scale) is seven in the most efficient situation. In such a case, the EQP is equal to 11. According to Tables 3 and 4, it seems that the efficient situations were realized in most sessions and periods, on average. Moreover, Figure 2 shows that it is likely that the average trading price (ATP) converges to the EQP of the efficient situation through periods in most sessions. When observing the average of ATPs of all sessions for each period, this trend becomes clearer because the price converges to 11 (Figure 4). Even the average numbers of vessels seem to reinforce the realization of efficiency (Figure 5).

Then, is it true that markets of ITQs work perfectly in realizing the efficient situation in terms of both quota prices and the vessel scales? We investigate the function of ITQs markets in detail in the following.

4.3 Prices

First, we examine whether or not subjects learn the quota market, and whether or not they are able to maximize their profits in the second stage in each period. In other words, we investigate whether or not the EQPs are realized given numbers of both types of vessels.

We calculate $ATP - EQP$ for each period in each session, and obtain the average of $ATP - EQP$ of all sessions for each period. The result is shown in Figure 6. It is clear that the difference fades away as time passes. We also use ATP/EQP to confirm the convergence of ATP to EQP, as shown in Figure 7.

Result 1: *The average trading price (ATP) converges to the theoretical equilibrium price (EQP) given numbers of both types of vessels, although it may take a long time to converge.*

We turn to one more important trend of trading prices. The correlation between ATP and $ATP - EQP$ of each period of all sessions was greater than 0.94, and that between ATP and ATP/EQP was greater than 0.85. If the numbers of vessels are fixed through periods and sessions, this result may be trivial. However, it does not necessarily hold when the numbers of both types of vessels change through periods. For example, if the difference is negative (positive) when the number of large-scale (small-scale) fishers is relatively large, the correlation coefficient could be negative. Thus, we establish the following result.

Result 2: *The strong positive correlation is observed between ATP and* $ATP - EQP$ *(or* ATP/EQP*).*

4.4 Choice of vessels

We now examine whether or not subjects chose vessels rationally. We estimate the following equation by both Probit and Logit models.

$$\begin{aligned} Invest_{i,t} &= c + \beta_1 (TP - EP)_{t-1} + \beta_2 TPV_{t-1} + \beta_4 \Pr ofit_{i,t-1} + \beta_5 risk1_i \\ &\quad + \beta_6 risk2_i + \beta_7 risk3_i + \beta_8 risk4_i + \varepsilon \end{aligned} . \tag{12}$$

$Invest_{i,t}$: The choice of Type 2 (large-scale) of subject *i* in period *t*.

$(TP - EP)_{t-1}$: The average trading price (ATP) minus the theoretical equilibrium price (EQP) in period *t–1*.

TPV_{t-1}: The variance of "prices" in period *t–1*.

Profit$_{t-1}$: The profit of subject *i* in period *t–1*.

risk : risk preference where risk 1–4 are different types of risk preferences.[12] These are values based on the pretest survey before the experiments and added on the model to control heterogeneous preferences on risks.

As noted in the theoretical part, we consider that the quota prices in the past periods influence the choice of the vessel of each subject in the present period. Moreover, a variable should be chosen according to the theory to extract the rational behavior. Thus, we chose the average trading price (ATP) minus the theoretical equilibrium price (EQP) in the previous period. Other independent variables are ordinary considered to be candidates that influence the choice of vessel type. Hypothetically, the variance (the profit) in the previous period negatively (positively) affects the choice of a large-scale vessel.

A summary of the results is shown in Table 5. According to these results, the difference between the ATP and the EQP in the previous period influenced the present choice of vessel type. This implies that expected prices of subjects depended on the quota prices in the past periods. The sign of the coefficient seems to be intuitive: the greater is the difference between the ATP and the EQP in the past, the less incentive subjects have to invest in large-scale vessels. In other words, they have an incentive to become sellers of quotas in the second stage.

We also verify that the simple correlation between Y and each of the followings show

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[12] For the meaning of the coefficients of risk factors, see Appendix B.

positive relationships: (a) the average of these differences in all of the past periods; (b) the ATP in the previous period; and (c) the average of the ATPs in all of the past periods. Similar to the difference between the ATP and the EQP, the results are significant.

Consequently, we conclude that the choices of vessels are rational in the following sense.

Result 3: *Vessels are chosen rationally, in the sense that, the greater is the average trading price (ATP) minus the theoretical equilibrium price (EQP) in the past periods, the less incentive subjects have to invest in large-scale vessels.*

4.5 The importance of quota prices in the first period

If the expected prices of subjects are formed according to trading prices in the past periods, the price in the first period (or in the first few periods) may affect trading prices in the ensuing periods. To confirm whether this type of influence exists, we observe the relationship between the ATP in the first period and the average of ATPs from period two through the last period in each session. The result is shown in Figure 8. It is likely that the ATP in the first period positively influences the ATPs in the ensuing periods.

This fact also indicates that the ATP in the first period is important for the numbers of both types of vessels determined in the ensuing periods. Figure 9 indicates that the ATP in the first period negatively influences the number of Type 2 (large-scale) vessels in the ensuing periods.

Result 4: *The ATP in the first period influences not only the ATPs but also the vessel scales in the ensuing periods.*

The upward bias of trading prices in the starting point of ITQ markets has also been pointed out in the literature (see Anderson (2004) and Anderson and Sutinen (2005, 2006)). Moreover, as noted in Result 2, a positive correlation was observed between ATPs and the difference between ATPs and EQPs. Thus, the trading prices in the starting point of an ITQ market are very important for the vessel scales to be determined efficiently. At least, it is likely that the deviation of trading prices from the EQP in the first period delays the vessel scales to become those when ATP is equal to EQP.

5. Initial Allocation: Results from Additional Sessions

In our basic sessions, quotas were allocated equally in the beginning of each period. As noted in Section 2, under perfect competition, the amounts of catches are not influenced by the initial allocations as far as the numbers of both types of vessels are given. However, it does not mean that the initial allocations do not affect vessel scales. Irrespective of vessel types, the expected profit of a fisher for any given numbers of both types of vessels increases, when her/his initial allocation increases. From (5)’ and (10), we obtain:

$$\frac{d\tilde{\Pi}_{i,j}}{d\bar{q}_j} = \tilde{r} > 0 \tag{13}$$

We focus on fisher h who chooses her/his own vessel type. Suppose that $\breve{n}_L$ other fishers have chosen large-scale vessels, and $(N - \breve{n}_L - 1)$ fishers have chosen small-scale vessels. Then, a small increase in her/his initial allocation increases her/his expected profit in the case in which s/he chooses a large-scale vessel by $\tilde{r}\left(\breve{n}_L + 1, \alpha\right)$. On the other hand, a small increase in her/his initial allocation increases her/his expected profit in the case in which s/he chooses a small-scale vessel by $\tilde{r}\left(\breve{n}_L, \alpha\right)$. From Hypothesis 1, it is clear that $\tilde{r}\left(\breve{n}_L + 1, \alpha\right) > \tilde{r}\left(\breve{n}_L, \alpha\right)$ holds unless α changes. Therefore, an increase in the initial allocation gives a fisher a stronger incentive to invest in a large-scale vessel. On the contrary, the smaller the initial allocation a fisher has, the more incentive s/he has to choose a small-scale vessel.

To confirm whether the numbers of both types of vessels are influenced by the initial allocations, we conducted two more series of eight sessions, which means that, in total, we conducted 16 additional sessions.[13] In these additional sessions, quotas were not allocated equally. We represent the first eight sessions as the A1 series, and the second eight sessions as the A2 series. In the A1 series, each of six subjects was given six quotas/coupons, and each of the other six subjects was given 10 quotas/coupons. On the other hand, in the A2 series, each of six subjects was given five quotas/coupons, and each of the other six subjects was given 11

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[13] These sessions were conducted at the Yokohama National University in February and March 2010.

quotas/coupons. Other details were completely the same as in the basic sessions, including TAC that was equal to 96.

First, Figure 10 indicates that the ATPs converge to the EQPs in both the A1 and A2 series, which implies that Result 1 holds. In the A1 series (A2 series), the correlation coefficient between ATP and $ATP - EQP$ of each period of all sessions was greater than 0.99 (0.91), and that between ATP and ATP/EQP was greater than 0.99 (0.76). These values indicate that Result 2 also holds.

When it comes to vessel choices (Result 3), in the A1 series, the effects of both quota prices in the past periods and the initial allocation are not statistically significant. On the other hand, in the A2 series, both variables influence the choice of vessel types significantly. Table 6 shows the results of Probit and Logit regressions for the A2 series. In these regressions, we added one more independent variable, "allocation dummy (Al_dummy in Table 6)", which is equal to one when a subject is given 11 coupons (initial allocation), and equal to zero when a subject is given five coupons. It is clear that this variable positively influences the incentive to choose a large-scale vessel. In other words, as shown in the theoretical analysis, the greater the initial allocation for a fisher, the greater incentive s/he has to invest in a large-scale vessel.

On the influence of the quota price in the first period on the quota prices and vessel scales in the ensuing periods (Result 4), we observe no clear correlation in the A1 series. On the other hand, in the A2 series, the quota price in the first period influences the prices in the ensuing periods because the correlation coefficient is 0.77. In the case of the effect on investment in large-scale vessels, the correlation coefficient is moderate (being –0.29).

By our combining the basic sessions with the additional two series of sessions, it is clear that fishers/subjects behaved rationally in the quota market: they learned the meaning of prices and transactions, and they sold or/and bought quotas so that their profits were maximized. Given the numbers of both types of vessels, this implies that the total cost of catching a certain amount of fish was minimized.

Moreover, from the basic sessions and the A2 series, we conclude that the behavior of the fishers on the choice of vessel type were rational in the sense that, the greater the value of the

ATP minus the EQP in the past periods, the less incentive subjects had to invest in large-scale vessels.

On the choice of vessel type and the effect of the quota price of the first period on the ensuing periods, the results of the A1 series were different from the basic sessions and the A2 series. The possible reason is as follows.

In the A1 series, the ATP converges to 13 which is higher than 11 to which the ATP converges in the basic sessions (Figure 11). It is likely that the upward bias of the quota prices arose and lingered over periods. Consider the case in which subjects with six initially allocated quotas choose Type 2 (large-scale) vessels and subjects with 10 initially allocated quotas choose Type 1 (small-scale) vessels. Subjects with Type 2 vessels catches more fish than those with Type 1 vessels. Thus, the amount of quota trading becomes large. On the other hand, in the case in which subjects with 10 initially allocated quotas choose Type 2 (large-scale) vessels and subjects with six initially allocated quotas choose Type 1 (small-scale) vessels, the amount of quota trading becomes small. This is because they do not need to make many deals to achieve the optimal catch for their own vessels. Then, depending on which case arises, the amounts of quota trading may vary drastically through periods. Thus, the quota prices easily become unstable and buyers are eager to obtain quotas, or speculation takes place. Consequently, it may be that the behavior of the subjects is not rational. Table 7 indicates that the variances of trading prices of the first five periods in the A1 series were relatively large as compared with the basic and the A2 series.

Contrary to the A1 series, the difference between a fisher with a larger initial allocation and a fisher with a smaller initial allocation is greater in the A2 series. Therefore, it is likely that the choices of vessel types by fishers are stable: the possibility that a fisher with a larger (smaller) initial allocation chooses a large-scale (small-scale) vessel is strong. In this case, drastic changes in the quota transactions through periods are less frequent.

The fact that some results of the A1 series are not significant does not mean subjects do not behave rationally; rather it means that initial allocations could play an important role in realizing efficient harvesting structure and quota trading.[14]

6. Concluding Remarks

In this paper, we use a laboratory experiment to examine (a) whether vessel scales are rationally chosen by using an experimental approach. Like other experimental studies on ITQs, we also examined (b) whether or not ITQ markets function well.

We obtained important information from our experiment, and extract some interesting results for fisheries management by using market mechanisms. First, the average trading price (ATP) converges to the theoretical equilibrium price (EQP) given numbers of both types of vessels, although it may take a long time to converge. In contrast to the results obtained in the literature, we verified that, even if vessel scales change through periods, subjects learn the market and the quota price converges to the EQP, on average. We also found that a strong positive correlation exists between the ATP and the variable, $ATP - EQP$ (or ATP/EQP).

Second, we found that vessels are chosen rationally in the sense that, the greater is the ATP minus the EQP in the past periods, the less incentive subjects have to invest in large-scale vessels. Moreover, the ATP in the first period could influence not only the ATPs but also the vessel scales in the ensuing periods.

Third, theoretically, the initial allocations do not matter in terms of efficiency, when the numbers of both large- and small-scale vessels are fixed, and when the quota market is perfectly competitive. We found, however, that it could influence the vessel scales significantly through two channels. The first channel is that increases in the initial allocations give fishers stronger incentive to invest in large-scale vessels. This effect arises because fishers are rational. The second channel is that the quota price may be unstable, and this situation influences the choice of vessel types by fishers. This effect may arise because fishers cannot carry out rational decision making.

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[14] Some previous studies support our finding. For example, Burtraw et al. (2001) found that initial allocation rules affect the cost effectiveness of emissions trading schemes. Tietenberg (2006) mentioned that initial allocations play an important role, not only on the fairness of the program but also on the cost effectiveness in practical implementation of emissions trading schemes.

Finally, for fisheries management, to realize the efficient vessel scales is an important task. ITQ regimes could help vessel scales to become efficient. Since the choice of vessels responds to the quota prices, even if the numbers of vessels in Nash equilibrium is different from those in the social optimum, some incentive schemes, such as subsidies, can be used to eliminate the gap. However, the results tells us whether or not the quota market functions well, or whether or not the EQP is realized in each period, plays a key role, not only for short-run efficiency, but also for long-run efficiency, in which the total social cost to catch a certain amount of fish is minimized.

There are other issues on the function of ITQ regimes. For example, uncertainty on fish prices and costs may also play an important role in determining the degree of efficiency under an ITQ regime. Moreover, exit from the fishing industry is also an important issue. To clarify the effects of those factors using laboratory experiments is a future task.

Appendix A: The number of both types of vessels and the quota price

In this Appendix, we neglect integer problems on the numbers of vessels.

Total differentiation of (6) and (7) with respect to n_L yields:

$$\begin{pmatrix} c_L'' & -c_S'' \\ n_L & N-n_L \end{pmatrix} \begin{pmatrix} dq_L^T/dn_L \\ dq_S^T/dn_L \end{pmatrix} = \begin{pmatrix} 0 \\ -q_L^T + q_S^T \end{pmatrix}. \tag{A.1}$$

Thus, we obtain:

$$\frac{dq_L^T}{dn_L} = -\frac{c_S''\left(q_L^T - q_S^T\right)}{\Omega}, \quad \frac{dq_S^T}{dn_L} = -\frac{c_L''\left(q_L^T - q_S^T\right)}{\Omega}, \tag{A.2}$$

where $\Omega = c_L'' \cdot \left(N - n_L\right) + c_S'' n_L > 0$. Note that these derivatives are negative. Thus, from (5), we obtain that:

$$\frac{dr}{dn_L} = \frac{c_L'' c_S''\left(q_L^T - q_S^T\right)}{\Omega} > 0. \tag{A.3}$$

Appendix B: Questionnaire

In the questionnaire, there were four questions on risk attitude following other psychological surveys.

1) What is the lowest probability of precipitation that you take an umbrella with you?

2) If you have an appointment to meet your friends, how much time before the time of the appointment do you get to the meeting place?

3) How often do you cross streets against the red light, when there is no traffic?

4) Do you usually care about lockups and fire? To what extent?

In Tables 5 and 6, "risk 1" through "risk 4" correspond to "question 1" through "question 4" above, respectively. For "risk 1" and "risk 4", we process the data so that the risk lovers (risk averters) get higher (lower) rates. On the other hand, for "risk 2" and "risk 3", we process the data so that the risk averters (risk lovers) get higher (lower) rates.

References

Anderson, C. M., M. A. Freeman, and J. G. Sutinen, 2008, A laboratory analysis of industry consolidation and diffusion under tradable fishing allowance management, in Todd, C. L., Kroll, S., and Shogren, L, J. eds., *Environmental Economics, Experimental Methods,* 29-46, Routledge.

Anderson,C. M., 2004, How institutions affect outcomes in laboratory tradable fishing allowance systems, *Agricultural and Resource Economics Review* 33(2), 193-208.

Anderson, C. M., and J. G. Sutinen, 2005, A laboratory assessment of tradable fishing allowances, *Marine Resource Economics*, 20, 1-23.

Anderson, C. M., and J. G. Sutinen, 2006, The effect of initial lease periods on price discovery in laboratory tradable fishing allowance markets, *Journal of Economic Behavior and Organization*, 61, 164-180.

Arnason, R., 1993, The Icelandic individual transferable quota system: a descriptive account, *Marine Resource Economics* 8, 201-218.

Burtraw, D., Palmer, K., Bharvikar, R., Paul, A., 2001, The effect of Allowance Allocation on the Cost of Carbon Emission Trading, Resource for the future discussion paper, 01-30.

Cason, T. N., L. Gangadharan, and C. Duke, 2003, Market power in tradable emission markets: a laboratory testbed for emission trading in Port Phillip Bay, Victoria, *Ecological Economics*, 46, 469-491.

Cason, T. N., and L. Gangadharan, 2006, Emissions variability in tradable permit markets with imperfect enforcement and baking, *Journal of Economic Behavior and Organization*, 61, 199-216.

Clark, I. N., P. J. Major, and N. Mollett, 1988, Development and implementation of New Zealand’s ITQ management system, *Marine Resource Economics 5*, 325-349.

Eythórsson, E., 2000, A decade of ITQ-management in Icelandic fisheries: consolidation without consensus, *Marine Policy* 24, 483-492.

FAO, 2008, the state of world fisheries and aquaculture, the Food and Agriculture Organization of United Nations, http://www.fao.org/fishery/sofia/en.

Fishbacher, U., 1999, z-tree – Zurich toolbox for readymade economic experiments, Working paper #21, Institute for Empirical Research in Economics, University of Zurich.

Gangadharan, L., A. Farrell, and R. Croson, 2005, Investment decisions and emissions reductions: results from experiments in emissions trading, Research Paper #942, Department of Economics, The University of Melbourne.

Gauvin, J. R., J. M. Ward, and E. E. Burgess, 1994, Description and evaluation of the wreckfish (polyprion amerianus) fishery under individual transferable quotas, *Marine Resource Economics*, 9, 99-118.

Geen, G.., and M. Nayar, 1988, Individual transferable quotas in the Southern bluefin tuna fishery: an economic appraisal, *Marine Resource Economics* 5, 365-387.

Godby, R. W., 1997, Emissions trading with shares and coupons when control over discharges is uncertain, *Journal of Environmental Economics and Management,* 32, 359-381.

Godby, R. W., 2000, Market power and emissions trading: theory and laboratory results, *Pacific Economic Review*, 5, 349-363.

Ledyard, J. O., and K. Szakaly-Moore, 1994, Designing organizations for trading pollution rights, *Journal of Economic Behavior and Organization*, 25, 167-196.

Managi, S., 2009, Capacity output and possibility of cost reduction: fishery management in Japan, RIETI Discussion Paper Series 09-E-040,
http://www.rieti.go.jp/jp/publications/dp/09e040.pdf.

Murphy, J. J., and J. K. Stranlund, 2007, A laboratory investigation of compliance behavior under tradable emissions rights: implications for targeted enforcement, *Journal of Environmental Economics and Management*, 53, 196-212.

Newell, R. G., J. N. Samchirico, and S. Kerr, 2005, Fishing quota markets, Journal of Environmental Economics and Management, 49, 437-463.

Squires, D., and J. Kirkley 1996, Individual transferable quotas in a multiproduct common property industry, *Canadian Journal of Economics* 29, 318-342

Tietenberg, T., 2006, Emissions Trading Principles and Practice, Washington DC, RFF press.

Van Boening, M.V., and N. T. Wilcox, 1996, Avoidable cost: ride a double auction roller coaster, *American Economic Review*, 86, 461-477.

Weninger, Q., 1998, Assessing efficiency gains from individual transferable quotas: an application to the Mid-Atlantic surf clam and ocean quahog fishery, *American Journal of Agricultural Economics* 80, 750-764.

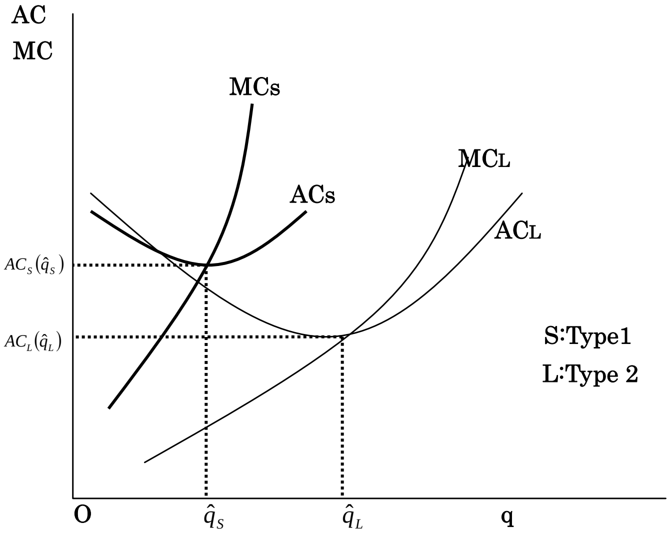

Figure 1. Cost Structure

fishing amount	Type1: Small scale		Type2: Large scale	
	Total cost	Marginal cost	Total cost	Marginal cost
0(fix cost)	20		80	
1	35	15	88	8
2	52	17	97	9
3	71	19	107	10
4	92	21	118	11
5	115	23	130	12
6	140	25	143	13
7	167	27	157	14
8	196	29	172	15
9	227	31	188	16
10	260	33	205	17
11	295	35	223	18
12	332	37	242	19
13	371	39	262	20
14	412	41	283	21
15	455	43	305	22
16	500	45	328	23
17	547	47	352	24
18	596	49	377	25
19	647	51	403	26
20	700	53	430	27

Table 1: Cost structures of both types of vessels

Number of Vessels	Theoretically Equilibrium Price (EQP)
Type1(S)=9, Type2(L)=3	5.5
Type1(S)=8, Type2(L)=4	7
Type1(S)=7, Type2(L)=5	9
Type1(S)=6, Type2(L)=6	9.5
Type1(S)=5, Type2(L)=7	11
Type1(S)=4, Type2(L)=8	11.5
Type1(S)=3, Type2(L)=9	12.5
Type1(S)=2, Type2(L)=10	13

Table 2: Theoretical equilibrium price (EQP)

Session	Average Trading Price (ATP)	Variance of price	Type 1 (S)	Type 2 (L)
1	11.64	102.25	5.1	6.9
2	10.34	18.04	4	8
3	8.10	94.58	4.5	7.5
4	11.58	40.22	5.4	6.6
5	14.31	207.19	5.8	6.2
6	9.20	56.86	4.3	7.7
7	15.48	109.93	6.2	5.8
8	15.62	1862.34	4.9	7.1
Average	12.03	311.43	5.025	6.975

Table 3: Average trading price (ATP), variance, and numbers of vessels of each session

Period	Average Trading Price (ATP)	Variance of price	Type 1 (S)	Type 2 (L)
1	12.94	88.33	4.75	7.25
2	14.20	104.59	5	7
3	13.53	263.17	4.875	7.125
4	12.63	61.69	5.125	6.875
5	11.79	81.72	5.125	6.875
6	10.95	49.41	5.5	6.5
7	10.99	69.11	5	7
8	10.23	26.86	4.75	7.25
9	12.29	2275.77	5.125	6.875
10	10.79	93.60	5	7
Average	12.03	311.43	5.025	6.975

Table 4: Average trading price (ATP), variance, and numbers of vessels of each period

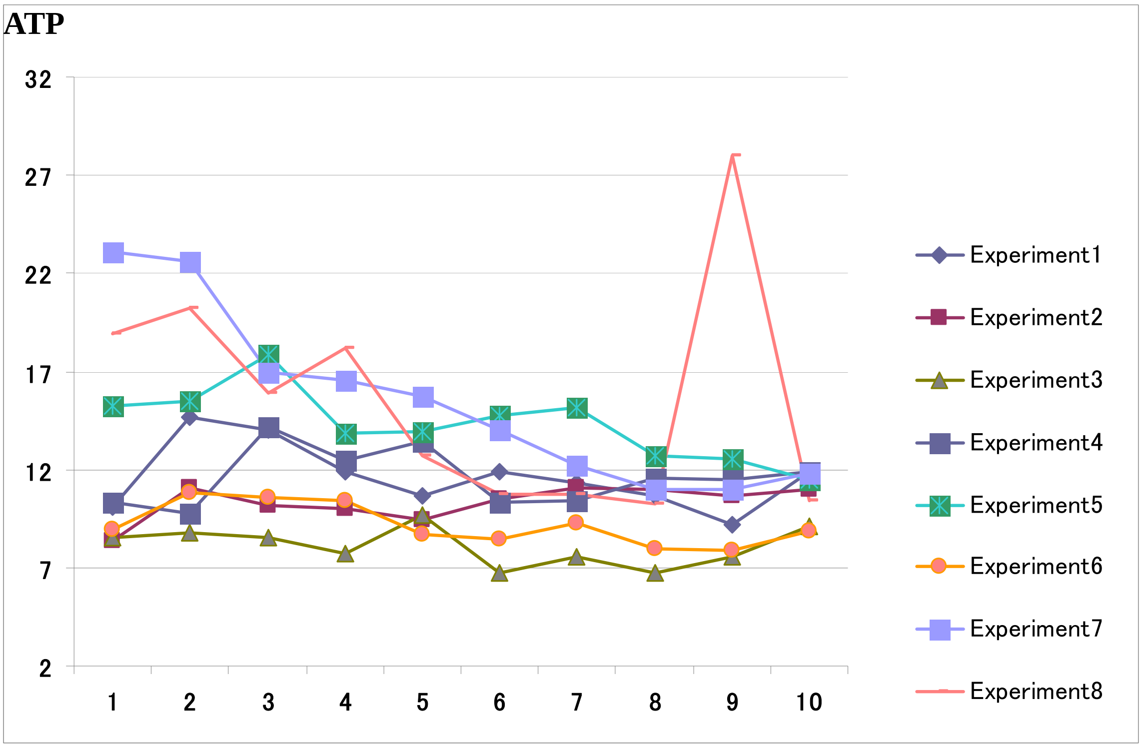

Figure 2: Price trend of each session

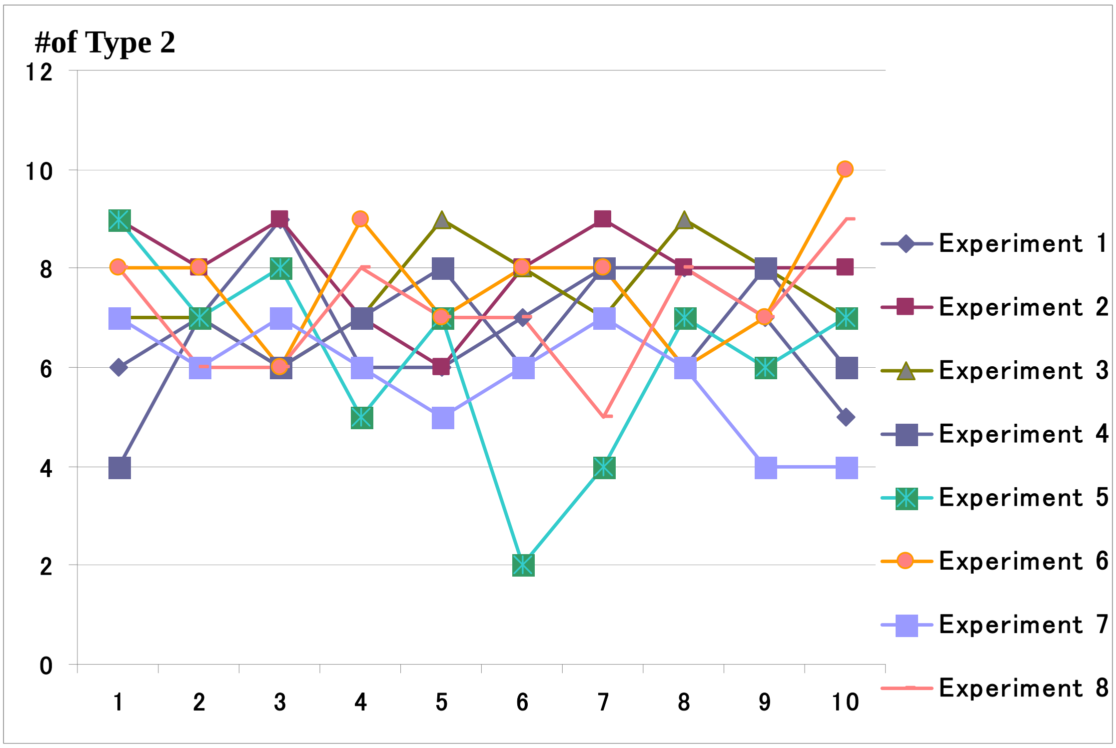

Figure 3: The trend of numbers of Type 2 (Large-scale) vessels of each session

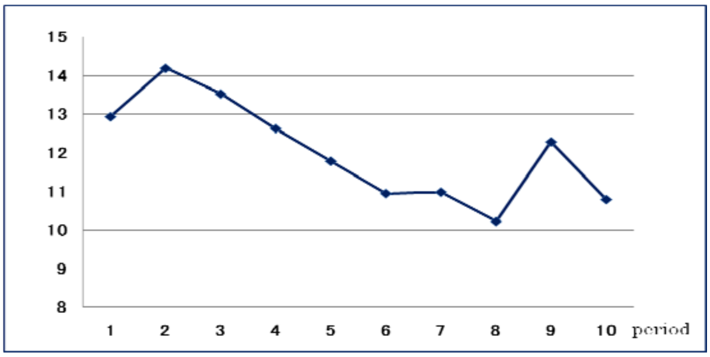

Figure 4: The average of ATP in each period including all sessions

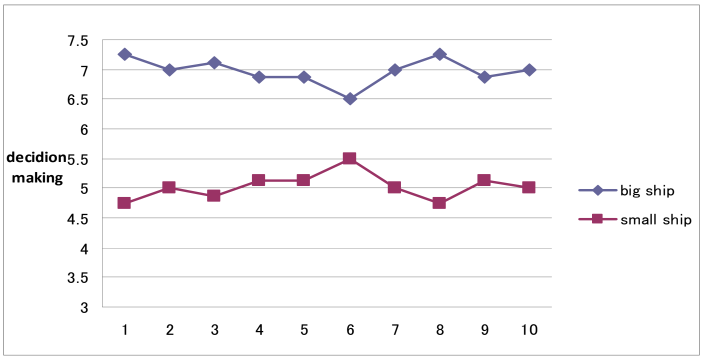

Figure 5: The average of the numbers of vessels in each period including all sessions

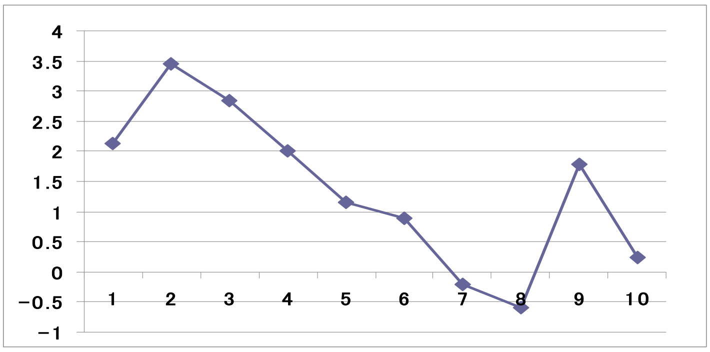

Figure 6: The average difference of ATP and EQP in each period

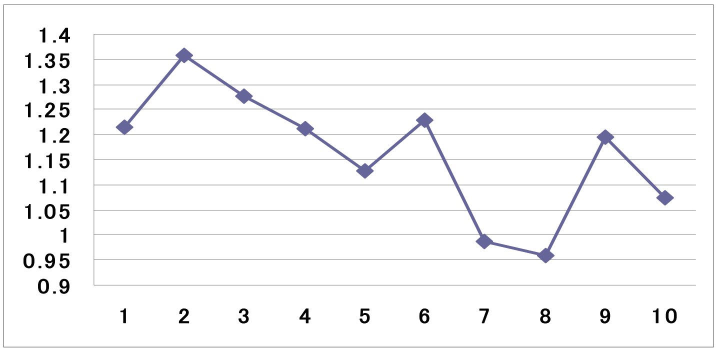

Figure 7: The average ratio of ATP to EQP in each period

Probit		
Variable	Coef.	z
TP-EP	-0.0239*	-1.91
TPV	0.00005**	2.03
Profit	0.0001	0.10
risk1	0.0038	0.44
risk2	0.0351*	1.90
risk3	0.6519***	2.74
risk4	-0.0000	-0.00
cons	-0.2860	0.01

Logit		
Variable	Coef.	z
TP-EP	-0.0379*	-1.88
TPV	0.0001*	1.95
Profit	0.0001	0.09
risk1	0.0060	0.43
risk2	0.0553*	1.86
risk3	1.0487***	2.72
risk4	-0.0005	-0.01
cons	-0.4520	-1.10

Observations: 720. Dependent Variable: Choice of Type 2 (Large-scale).
Note: *Significant at 10% level, **Significant at 5%level, ***Significant at 1% level by t-test.

Table 5: The effect of quota prices on the choice of vessel

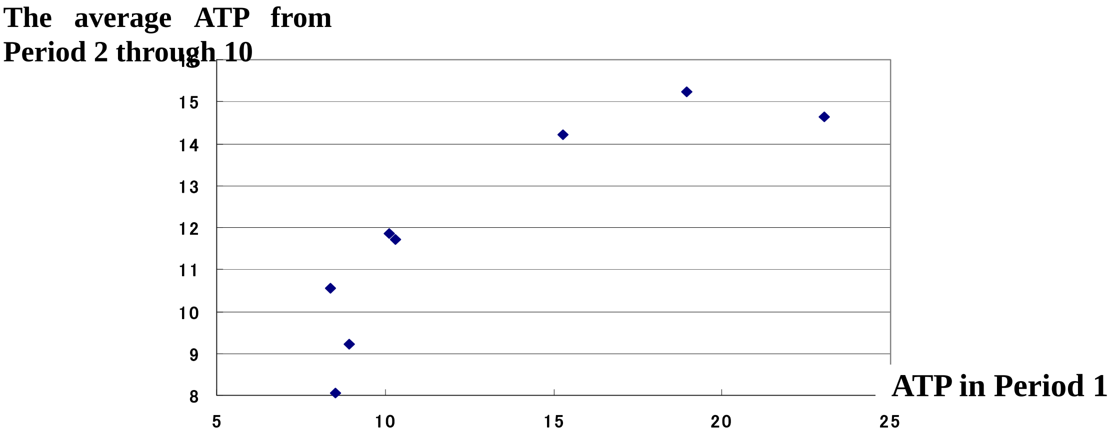

Figure 8: The affect of ATP in period 1 on ATPs in the ensuing periods.

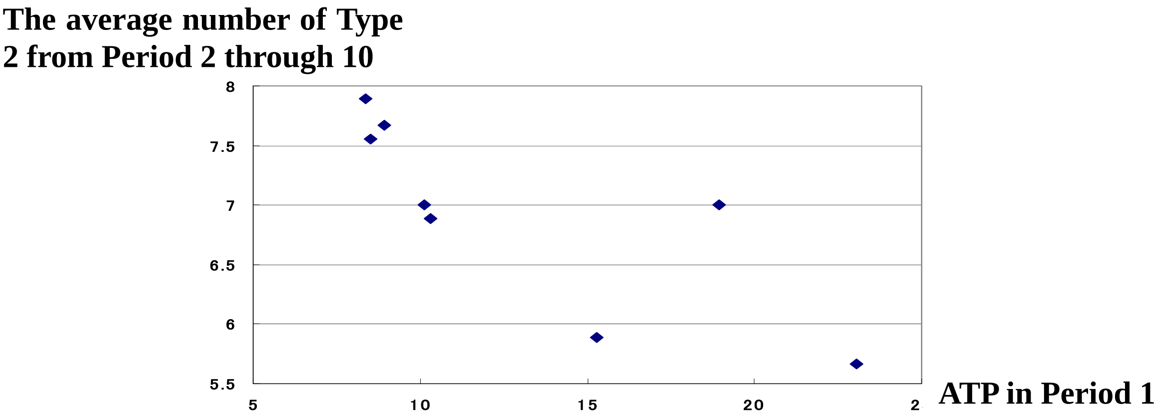

Figure 9: The effect of ATP in Period 1 on Type 2 vessels in the ensuing periods.

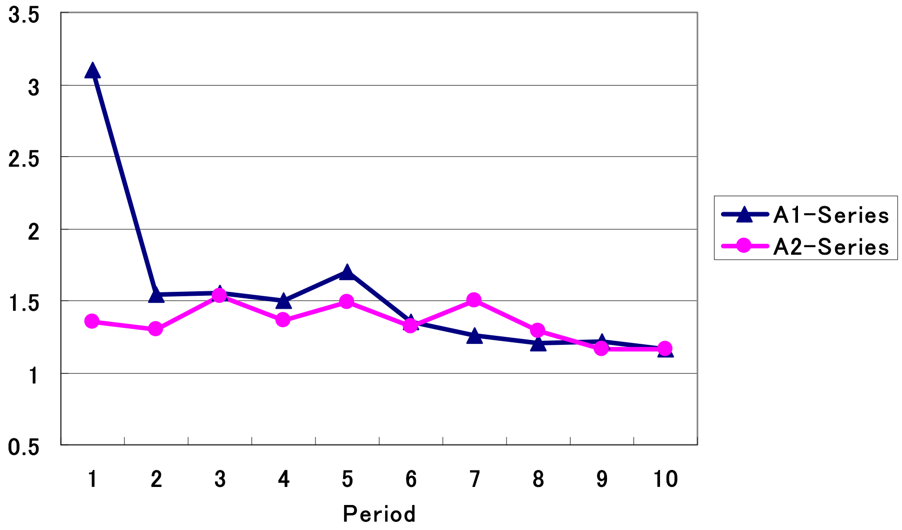

Figure 10. The average ratio of ATP to EQP in each period in A1 and A2 series

Probit		
Variable	Coef.	z
TP-EP	-0.0176*	-1.75
TPV	-0.0000	0.01
Profit	0.0000	0.10
Al-dummy	0.5637***	5.62
risk1	0.0022	0.26
risk2	-0.0164*	-1.96
risk3	-0.0828	-0.40
risk4	0.0233	0.47
cons	0.0174	0.07

Logit		
Variable	Coef.	z
TP-EP	-0.0283*	-1.73
TPV	-0.0000	-0.02
Profit	0.0004	0.05
Al-dummy	0.9115***	5.57
risk1	0.0039	0.28
risk2	-0.0265**	-1.96
risk3	-0.1431	-0.43
risk4	0.0390	0.49
cons	0.0338	0.08

Observations: 828. Dependent Variable: Choice of Type 2 (Large-scale).
Note: *Significant at 10% level, **Significant at 5%level, ***Significant at 1% level by t-test.

Table 6: The effect of quota prices and initial allocation on the choice of vessel in A2 series

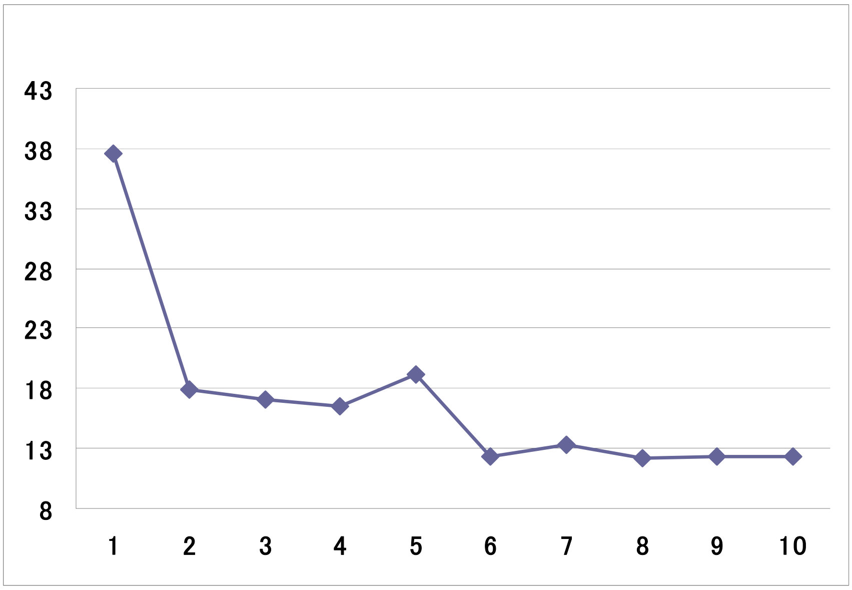

Figure 11: The average of ATPs in each period including all sessions in A1 series.

Period	Basic	A1	A2
1	88.33	15413.17	56.92
2	104.59	127.54	81.82
3	263.17	101.72	131.08
4	61.69	139.56	65.03
5	81.72	2378.94	131.23
6	49.41	38.24	46.27
7	69.11	83.83	404.18
8	26.86	32.12	60.42
9	2275.77	34.77	68.48
10	93.6	81.00	38.45
Average	311.43	1843.09	108.389

Table 7: Variances of Trading Prices