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A laboratory assessment of the choice of vessel size under individual transferable quota regimes*

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This paper examines the effect of individual transferable quota regimes on technology choice, such as choice of vessel size, by using the laboratory experiment method. We find that even if vessel sizes change over time, the quota price can converge to the fundamental value conditioned on the vessels chosen. We also find that subjects choose their vessel type to maximise their profits based on the quota trading prices in the previous period. This result implies that the efficiency of quota markets in the beginning period is important because any inefficiency in quota markets may affect vessel sizes in ensuing periods. Moreover, we find that the initial allocations may significantly influence vessel sizes through two channels: first, a higher initial allocation to a subject increases the likelihood that the subject invests in a large-sized vessel; second, the quota price may be higher and more unstable under unequal allocation than under equal allocation; thus, whether the allocation is equal influences subjects' choice of vessel type.

Key words: double auction, experiment, fishery, Individual transferable quotas, technology choice.

1. Introduction

Individual transferable quotas (ITQs) are believed to achieve an efficient level of fishing activity and proper resource management simultaneously.[1] Previous studies conclude that an ITQ regime is a good tool for encouraging an efficient fish catch level and for preventing the collapse of fisheries (OECD 1999; Costello *et al*. 2008; Arnason 2009).

Many other studies have analysed the important aspects of ITQ regimes, including the instability of quota prices (Newell *et al*. 2005), the existence of

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[1] ITQ regimes have been used in several countries, such as New Zealand, Iceland, and Australia, since the 1980s. For empirical case studies, see Clark *et al*. (1988), Eythórsson (2000), Gauvin *et al*. (1994), and Weninger (1998).

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risk-averse fishers (Bergland and Pedersen 2006) and inefficiency of quota markets caused by market power (Anderson 1991). However, little attention has been paid explicitly to changes in the sizes of vessels. One exception is Vestergaard (2005), who demonstrates theoretically that the existence of sunk costs delays the achievement of an optimal fleet structure.

Productivity changes have been observed in fisheries (Jin *et al.* 2002; Hannesson 2007). Technology is an important determinant of productivity, and in the context of the fishing industry, vessel size is important for understanding technology choice. Vessel sizes vary widely, even among vessels of the same type (e.g. multipurpose vessels or part-time fleets; Arnason 1993). In some fisheries, there are too many small-scale traditional fishers, whereas in other fisheries, the existing vessels are too large, implying an excess investment by each fisher.[2] Because each fisher may choose the size of her/his own fishing vessel, the introduction of an ITQ regime may influence fishers to adjust the size of their vessels. Because an inefficient fisher gains more from selling quotas to other efficient fishers than from harvesting by herself/himself, each fisher has less incentive to keep/buy an inefficient vessel when an ITQ regime exists than when no such regime exists.[3]

In this study, we analyse the effect of ITQs on choice of vessel size by using the laboratory experiment method. In particular, this paper examines whether ITQ markets (or the price of quotas) affect harvesters' choice of vessel size, where human subjects play the role of fishers. In the literature, the laboratory experiment method has helped to identify efficient emissions-trading policies. For example, Ledyard and Szakaly-Moore (1994) and Cason and Plott (1996) analyse the efficiency of the auction mechanism for trading permits. Cason and Gangadharan (2006) and Stranlund *et al.* (2011) analyse compliance behaviour under imperfect monitoring. Experimental approaches, beginning with the analyses conducted by Christopher Anderson, are also effective for analysing the efficiency of ITQ regimes. For example, Anderson (2004) and Anderson and Sutinen (2005) examine the efficiency of alternative ITQ rules. Price volatility is identified in several schemes, and the mitigation of price volatility is an important topic in the literature. Anderson and Sutinen (2006) show that the introduction of initial lease periods mitigates quota price instability through various mechanisms. Moreover, Anderson *et al.* (2008) study the relationship between cost structures and the market share distribution among operators, and Moxnes (2012) compares the effectiveness of schemes between ITQs and auctioned seasonal quotas by using a laboratory experiment. However, choice of vessel size has not been explicitly examined in a laboratory experiment.

[2] For example, Yagi and Managi (2011) find substantial inefficiency in the Japanese fishing industry and indicate that the introduction of ITQs would lead to large potential cost reductions.

[3] For case studies, see Arnason (1993) and Geen and Nayar (1988), who evaluate the effect of introduction of ITQs on the efficiency of vessel sizes for Iceland and Australia, respectively.

We find that the average trading price converges to the theoretical equilibrium price (EQP) given the observed capital levels. We then demonstrate that subjects choose their own vessels such that their profits increase based on the quota trading prices in the previous period. This result implies that the efficiency of quota markets in ITQ programs in the beginning period is important because any inefficiency in the quota markets may affect vessel sizes in ensuing periods, which may lead to persistently inefficient vessel sizes. Moreover, initial allocations may influence vessel sizes significantly through two channels: first, a higher initial allocation to a subject increases the likelihood that the subject invests in a large-sized vessel; second, the quota price may be higher and more unstable under unequal allocation than under equal allocation; thus, whether the allocation is equal influences subjects' choice of vessel type.

This paper is structured as follows: Section 2 describes the theoretical background. Section 3 outlines the experimental design. Section 4 examines the results of the experiments, namely, the convergence of quota prices to EQPs and choice of vessel size. Section 5 provides concluding remarks.

2. Theoretical background

Consider a fishery with N fishers. Each fisher engages in fishing with one vessel that is large or small size (t*ype* L or S, respectively) and harvests the fish stock of a single species. The cost structure of each type of vessel is as follows:

$$C_\theta(q_{i,\theta}) = c_\theta(q_{i,\theta}) + F_\theta, c'_\theta > 0, c''_\theta > 0, \tag{1}$$

where $q_{i,\theta}$ denotes the catch size of fisher i with vessel type $\theta(\theta = L,\ S)$. Moreover, c_θ and F_θ denote the variable cost and the fixed cost of vessel type θ, respectively.

At stage 0, the government sets the total allowable catch (TAC), denoted by $\bar{Q}$, and determines the initial allocation for each fisher. It is assumed that the price of fish, which is denoted by p, is constant. Note that the price of fish is different from the price of the quota. The quota price, which is denoted by r, is determined endogenously.

We then consider a two-step determination of the harvesting structure. In the first stage, given the initial allocation, each fisher chooses the type of vessel that he/she 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 that he/she holds.[4] Quotas are transacted in a perfectly competitive market.

As a benchmark, we consider a subgame perfect Nash equilibrium (SPNE) and solve the determination of the harvesting structure by backward induction. In the second stage, given the price of quotas, each type of fisher

[4] It is assumed that both new entry and exit do not occur because of the initial costs of entry and the costs of switching to other industries.

determines the catch size and, accordingly, the quota amount that he/she buys (or sells) to maximise his/her profit. The profit function at the second stage is given by:

$$\pi_{i,\theta}\left(q_{i,\theta}\right) = p(\bar{Q})q_{i,\theta} - C_{\theta}\left(q_{i,\theta}\right) - r \cdot \left(q_{i,\theta} - \bar{q}_i\right), \theta = L, S, \tag{2}$$

where $\bar{q}_i$ denotes the initial allocation for fisher i. The first-order condition is given by $p(\bar{Q}) - c'_{\theta} - r = 0$, and the demand for the quota of each fisher is given by $q_{i,\theta} = q_{\theta}(r)$. Because we assume that $c''_{\theta} > 0$, the demand curves for quotas are downward sloping. We thus obtain the equilibrium outputs and the quota price, which are represented as $q^*_{\theta}(n_L, \bar{Q})$ $(\theta = L, S)$ and $r^*(n_L, \bar{Q})$, respectively.[5] It is noted that the catch sizes are not influenced by the initial allocations $(\bar{q}_i)$, as far as the numbers of both types of vessels are fixed. Hereinafter, r* is referred to as the theoretical EQP.

In the first stage, each fisher chooses his/her vessel type such that his/her profit is maximised. Although fishers' profits depend on the numbers of both types of vessels and the TAC level, we fix the total number of fishers and the TAC level. Therefore, the profit at the first stage depends on the number of large-scale fishers only:

$$\Pi_{i,\theta} = p\, q^*_{\theta}(n_L) - C_{\theta}\left(q^*_{\theta}(n_L)\right) - r^*(n_L) \cdot \left(q^*_{\theta}(n_L) - \bar{q}_i\right), \theta = L, S,$$

where $\Pi_{i,\theta}$ denotes the profit of each fisher in the beginning of the first stage. Then, when the following two conditions are satisfied, n^{**}_L and $n^{**}_S \left(= N - n^{**}_L\right)$ are numbers of vessels in the SPNE in which no fisher has an incentive to change his/her own vessel type:

$$\Pi_L\left(n^{**}_L + 1\right) < \Pi_S\left(n^{**}_L\right), \Pi_S\left(n^{**}_L - 1\right) < \Pi_L\left(n^{**}_L\right) \tag{3}$$

As shown by Anderson and Sutinen (2005) and Newell *et al.* (2005), however, the quota prices in the second stage are not necessarily consistent with the values expected by theory. The deviation of quota prices from the theoretical values may not be randomly generated: there may be a persistent bias in quota prices, which would be caused by several factors, such as endowment effects. The quota price in the second stage is uncertain at the starting point of the first stage from the viewpoint of each fisher: it may deviate from the EQP that is theoretically expected given the numbers of both types of vessels. In such a case, each fisher chooses his/her own vessel to maximise the expected profit. Then, if initial allocations are determined such that large-scale (small-scale) fishers become buyers (sellers) of quotas, the following relationship generally holds: as the expected quota price increases,

[5] More precisely, the first-order condition is given by $p(\bar{Q}) - c'_{\theta} - r = 0$. When $c'_L < c'_S$ for any given catch size, $q^*_L > q^*_S$ holds. Moreover, in such a case, an increase in the number of large-scale fishers necessarily increases the quota price because the total demand for quotas increases.

each fisher has less incentive to invest in a large-sized vessel for any given number of both types of vessels chosen by other fishers.

For example, consider the following situation. At the beginning of the first stage, the possible quota price in the second stage ($\bar{r}$) is uniformly distributed, i.e., $\bar{r} \epsilon [r'(n_L) + \alpha, r^n(n_L) + \alpha]$, where $r^n > r^* \geq r' > 0$ and $\alpha > 0$.[6] α denotes the factor that positively affects the expected quota price. For example, upward deviations of the quota prices in previous periods are likely to positively influence the expected quota price. When the quota prices are biased upward only, $r^* = r'$ holds. Therefore, each fisher chooses a vessel type to maximise his/her own expected profit:

$$E\left[\Pi_{i,\theta}(n_L)\right] = \int_{r'+\alpha}^{r''+\alpha} \frac{\pi_{i,\theta}(y, \bar{q}_i)}{r'' - r'} dy, \theta = L, S, \tag{4}$$

where $\pi_{i,\theta}(y, \bar{q}_i) = p\, q_{i,\theta}(y) - C_\theta\left(q_{i,\theta}(y)\right) - y \cdot \left(q_{i,\theta}(y) - \bar{q}_i\right)$. Suppose that α increases, which implies an increase in the expected quota price. Then, on the basis of the envelope theorem, the effects on the expected profits given the number of large-sized vessels are obtained as follows:

$$\frac{dE\left[\Pi_{i,L}\right]}{d\alpha} = \frac{\pi_{i,L}(r'' + \alpha) - \pi_{i,L}(r' + \alpha)}{r'' - r'}, \tag{5a}$$

$$\frac{dE\left[\Pi_{j,S}\right]}{d\alpha} = \frac{\pi_{j,S}(r'' + \alpha) - \pi_{j,S}(r' + \alpha)}{r'' - r'} \tag{5b}$$

When a fisher is a seller (buyer) of quotas, a higher (lower) quota price implies higher profits for him/her, given the number of both types of vessels. Therefore, if initial allocations are determined such that large-scale fishers become buyers of quotas and small-scale fishers become sellers of quotas, (5a) is negative, whereas (5b) is positive. Thus, as the expected quota price increases, fishers have a greater incentive to invest in small-sized vessels and to be sellers of quotas.

3. Experimental design

3.1. Sessions

We conducted eight basic sessions, in each of which 12 subjects traded quotas in a computerised double auction. All the subjects were under 30 years of age

[6] Note that we are not deriving predictions from an equilibrium model. We consider a type of adaptive learning model demonstrated by Cooper *et al.* (1997a,b). For example, consider the following situation. Each subject considers that there is the possibility that other subjects have more efficient technology for both sizes of vessels or that some of the other subjects are irrational in the quota market. Then, each subject's beliefs are updated based on his/her own outcome, the numbers of both types of vessels, and the quota prices in the previous period.

and were mainly undergraduate and vocational school students. The subjects participated in only one session and were paid an average of $35, based on an exchange rate of 90 Japanese yen = 1 US dollar. At the beginning of each session, the subjects read the instructions for approximately 10 minutes. In this experiment, each session included 10 periods, with each period divided into two stages.

At the beginning of each period, each subject was given an *initial allocation*.[7] In the basic sessions, each subject was given eight quotas/coupons as the initial allocation, implying a TAC level of 96. He/she was also given a sheet that provided the fixed and marginal costs of both types of vessels, *Small* and *Large* (see Table 1).

In the first stage (*investment decision stage*), each subject chose between a small and a large fishing vessel. In the second stage (*quota trading stage*), each subject was able to adjust his/her quota holdings by buying and/or selling quotas in a double auction scheme. To familiarise the subjects with the experiments, we ran two training periods before running the paying periods.

We use technical terms that are specific to fisheries to describe the experimental design and the results in this paper. However, more neutral terminology was used in the experiments with the subjects. For example, we referred to a fish quota as a *coupon*. Moreover, we referred to a small-sized vessel as *Type 1* and a large-sized vessel as *Type 2*. We conducted the experiment by using the University of Zurich's z-Tree program (Fischbacher 2007).[8]

As noted in Section 2, under perfect competition, catch sizes are not influenced by the initial allocations, as far as the numbers of both types of vessels and the total quota amount are fixed. However, this independence does not mean that the initial allocations do not affect the vessel sizes. Irrespective of the vessel type, a subject's expected profit for any given number of both types of vessels increases when his/her initial allocation increases. In the case of a uniform distribution of quota prices, represented as (4), we obtain the following: [9]

[7] In this experiment, quotas were allocated to the subjects exogenously. In the real world, however, quotas may sometimes be allocated according to fishing history, which is presumably affected by vessel size. In such a case, fishers may have an incentive to control the initial allocation endogenously by changing their own vessel sizes. However, unlike the case of emissions permit trading, in the case of ITQs, there are important factors that cannot be controlled by fishers and that influence the initial allocation. For example, climate and the biological behaviour of fish species affect the TAC and, accordingly, the initial allocation. Thus, in the present experimental setting, we assume that initial allocation is exogenous when fishers choose their vessel size.

[8] These sessions were conducted at Yokohama National University on September 7th through 9th, 2009, and January 18th, 2010. Each session lasted approximately one and a half hours.

[9] In general, various types of distributions of quota prices can exist. The uniform distribution here is a guideline.

Table 1 Cost structures of both types of vessels

Fishing amount	Small		Large	
	Total cost	Marginal cost	Total cost	Marginal cost
0 (fixed 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

$$\frac{dE\left[\Pi_{i,\theta}\right]}{d\bar{q}_i} = \hat{r} > 0, \tag{6}$$

where $\hat{r}$ denotes the expected quota price. This implies that a larger allocation leads to greater profit. Moreover, it is interesting that a higher expected quota price magnifies this effect.

We focus on subject h, who chooses his/her own vessel type. Suppose that $\breve{n}_L$ other subjects have chosen large-sized vessels and that $(N - \breve{n}_L - 1)$ subjects have chosen small-sized vessels. Then, a small increase in subject h's initial allocation increases his/her expected profit by $\hat{r}(\breve{n}_L + 1, \alpha)$ when he/she chooses a large-sized vessel and by $\hat{r}(\breve{n}_L, \alpha)$ when he/she chooses a small-sized vessel. It is clear that $\hat{r}(\breve{n}_L + 1, \alpha) > \hat{r}(\breve{n}_L + \alpha)$ holds because an increase in the number of large-sized vessels increases the total demand for quotas. Therefore, an increase in the initial allocation gives a subject a stronger incentive to invest in a large-sized vessel. In contrast, a subject with a smaller initial allocation has more incentive to choose a small-sized vessel.

To determine whether the numbers of both types of vessels are influenced by the initial allocations, we conducted two more series of eight sessions. Therefore, we conducted 16 additional sessions in total.[10] In these additional

[10] These sessions were conducted at Yokohama National University on January 25th and 26th and February 2nd, 15th, 16th, 23rd and 24th, 2010.

sessions, the quotas were not allocated equally. We denote 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. Meanwhile, in the A2 series, each of six subjects was given five quotas/coupons, and each of the other six subjects was given 11 quotas/coupons. Other details were exactly the same as those in the basic sessions, including a TAC level of 96.

3.2. Investment decision stage

In the first stage, each subject chose one production method between *Small* and *Large*, which we call *investment* hereinafter. The fixed cost of *Small* is smaller than that of *Large*, whereas the marginal/variable cost of *Small* is higher than that of *Large* for any given catch size $(C'_L < C'_S)$. Moreover, a large-sized vessel is more efficient than a small-sized vessel in the sense that the minimum average cost for a large-sized vessel is smaller than that for a small-sized vessel.

In the real world, vessels are a type of sticky capital. Therefore, if we consider the length of a period to be very short, only a small number of fishers can change their vessels in each period. Nevertheless, every subject can change vessels in each period in our experiment. The reason that we use this setting is as follows. If we consider a period length that is relatively long, then every fisher changes vessels in each period. In this sense, our experiment generates comparative statics out of a dynamic equilibrium. This is a more flexible process than what is observed in reality. However, we are interested in examining how industry dynamics play out over the long run.

In this experiment, the fish price was fixed to 30.[11] According to the cost structures of both types, five subjects would choose *Small*, and seven subjects would choose *Large* in the SPNE in the basic, A1 and A2 series.[12] In the present setting, because there is no entry/exit, this combination of vessel numbers is also the most efficient combination. Thus, the total cost of producing 96 units is minimised in the SPNE. In each period, each subject was able to observe the investment result, which is the number of both types of vessels, on his/her own display from the end of the first stage through the second stage.

3.3. Quota trading stage

In the second stage, the subjects were able to adjust their quota holdings by buying and/or selling quotas/coupons in the double auction scheme. Each

[11] Note again that the fish price is the price of output, which is different from the quota price.

[12] There are also mixed-strategy equilibria. One of them is a symmetric equilibrium: each subject chooses a large-sized vessel with a probability of 0.6447 and a small-sized vessel with a probability of 0.3553. In this case, the most likely number of large-sized vessels is eight, and the second most likely number is seven.

subject's profits are determined by how many quotas he/she holds after trading and by how many quotas he/she buys/sells. In the basic sessions, the initial quota is allocated equally to all fishers, and the marginal/variable cost of *Small* is higher than that of *Large* for any given catch size. Thus, the demand for quotas of *Large* is necessarily greater than that of *Small*, given the quota price. Then, it is clear that subjects who chose *Small* also choose to sell and that subjects who chose *Large* also choose to buy quotas in the second stage because they transact quotas to maximise their own profits. In the present setting with the cost structures of both vessel types, in the SPNE, subjects who chose *Small* would sell five or six quotas/coupons, subjects who chose *Large* would buy three or four quotas/coupons, the price of a quota/coupon would be 11, and the profit for each subject would be 74. Even in the two additional series of sessions, the equilibrium quota price would be 11 because the numbers of both types of vessels in the SPNE are the same as those in the basic sessions. However, because the quotas are not equally allocated to subjects in the additional series, the selling and buying quantities of quotas would vary across the subjects.

The quota market was open for 3 minutes in the quota trading stage of each period. A deal was made whenever a buyer accepted the current bid or a seller accepted the current ask. When a deal was made, all of the current bids and asks on the screen were deleted, and the subjects began to propose new bids and/or asks. The history of trading prices was displayed on the screen.

4. Results

First, it should be noted that throughout the figures and tables, we have removed outliers and replaced them by the averages of the samples. In the present analysis, we define an outlier trade as a trade with a price above 50. See Table 2 for the average number of outliers in each period.

Because the subjects were able to choose the types of vessels in each period, the predicted EQP depended on the combination of numbers of both types of vessels. The list of predicted EQPs is shown in Table 3. Some of these values are not integers because there is more than one possible EQP.

A summary of the results is shown in Figures 1–3. As noted in the previous section, in the SPNE, the number of subjects who would choose *Small* is five, and the number of subjects who would choose *Large* is seven. In such a case, the EQP is equal to 11.

Table 2 The average number of outliers and the percentage

	Average number of outliers	Percentage of outliers (outlier/total trading)
Basic	0.488	0.746%
A1	0.850	1.232%
A2	0.413	0.578%

Table 3 Theoretical equilibrium price (EQP)

Number of vessels	Theoretically EQP
Small = 9, *Large* = 3	5.5
Small = 8, *Large* = 4	7
Small = 7, *Large* = 5	9
Small = 6, *Large* = 6	9.5
Small = 5, *Large* = 7	11
Small = 4, *Large* = 8	11.5
Small = 3, *Large* = 9	12.5
Small = 2, *Large* = 10	13

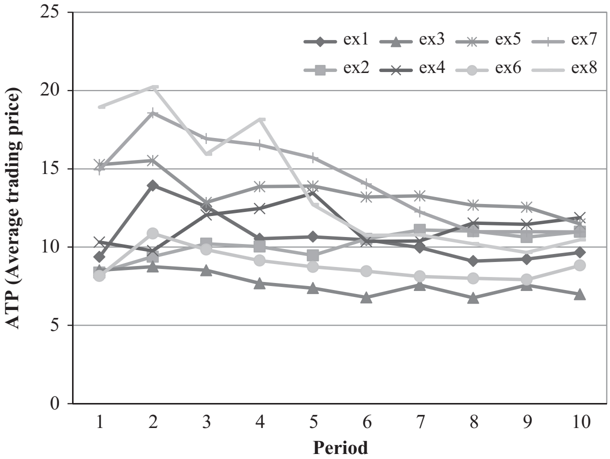

Figure 1 Price trend of each session in the basic series.

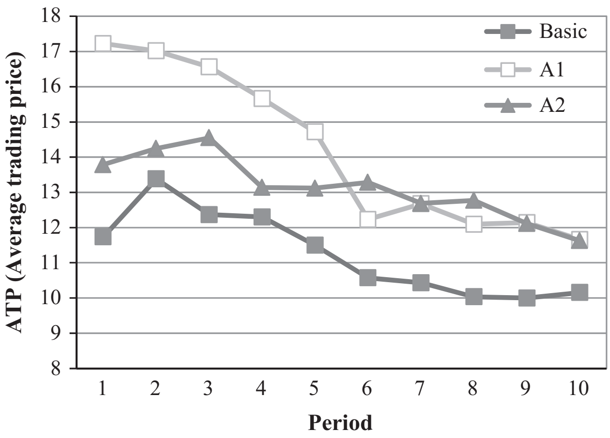

Figure 2 The average of average trading price (ATP) in each period including all sessions.

First, let us examine the results of the basic sessions. According to Figure 1, it appears that the average trading price (ATP) converges to the EQP in the SPNE over the periods. When observing the average of the ATPs

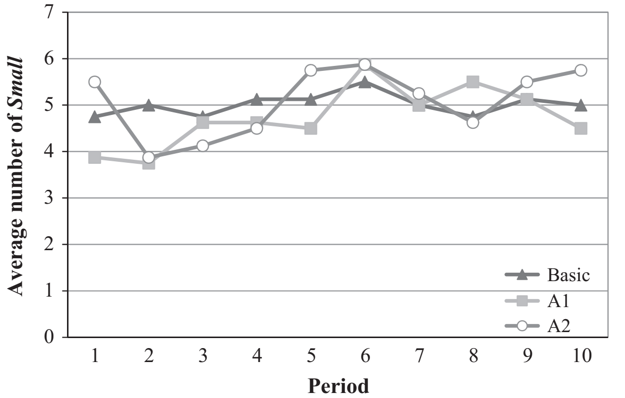

Figure 3 The average number of *Small* in each period.

of all sessions for each period (Figure 2), we find that this trend becomes clearer because the price converges to 11. Moreover, even the average numbers of vessels appear to reinforce the realisation of the expected equilibrium situation in which the number of subjects who would choose *Small* and *Large* is five and seven, respectively (Figure 3).

In the additional series, the averages of the ATPs are slightly higher than those in the basic sessions. However, they appear to converge, and the average number of subjects who choose *Small* does not appear to be different from the number of subjects who would choose *Small* in the SPNE (Figure 3). We investigate the functioning of ITQ markets in detail in the following subsection.

4.1. Convergence of quota prices

First, we examine whether subjects learn how the quota market operates and whether they are able to maximise their profits in the second stage in each period. In other words, we investigate whether the EQPs are realised, given the observed numbers of both types of vessels. We calculate $ATP - EQP$ for each period in each session and obtain the average of $ATP - EQP$ for all sessions for each period. The result is shown in Figure 4. The difference appears to clearly decline over time.

To investigate convergence processes more thoroughly, Myagkov and Plott (1997) suggest an econometric model that explicitly uses data on trading prices. In this study, we apply this econometric model to estimate the convergence process of the permit price of each treatment. Specifically, the model for estimation is given by:

$$r_{k,t} = \sum_{l=1}^{8} \beta_l D_l + \alpha\left(\frac{t-1}{t}\right) + u_{k,t}, \qquad (7)$$

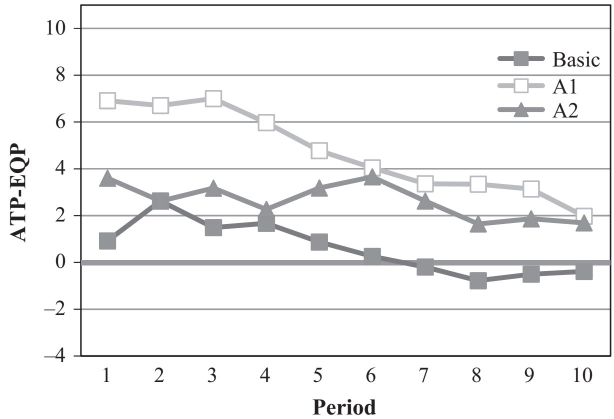

Figure 4 The difference between average trading price and EQP in each period.

where $r_{k,t}$ is the permit price of period t in session k, D_l is a dummy variable that takes the value one for session l and zero otherwise, β_l is a parameter that indicates the price level at the starting point of the convergence process, α is the price level at convergence, and $u_{k,t}$ is a random disturbance term that is assumed to be distributed normally with a zero mean. Regarding the price variable, we use ATP and $ATP - EQP$ for each trading period. We allow for first-order serial correlation and heteroskedasticity in the estimation.

Our estimation results in Table 4 show that the trend in the ATP in the basic series converges toward the quota price in the SPNE. Meanwhile, the ATPs in series A1 and A2 do not converge toward the EQP.

Result 1: Even though vessel sizes change over time, the quota price converges to the EQP conditioned on the vessels chosen in the basic series.

Three points should be noted. First, Anderson and Sutinen (2006) demonstrate that wide price variation occurs within multiple trading periods. Period-to-period speculation may cause this large variance, and this finding can be applied to the short-run price variation problems of quota markets in the real world. In contrast, convergence in our experiment implies that within-season price variation becomes smaller over time. This finding may also be applied to the long-run price variation problems of quota markets in the real world.

Second, according to Smith (1962), markets converge from above when consumer surplus is greater than producer surplus and/or when the supply curve is more elastic than the demand curve.[13] The market in our experiment,

[13] This point was mentioned by a journal referee, and we are grateful for this insightful suggestion.

Table 4 Convergence test of quota prices without outliers

	Basic		A1		A2	
	ATP	ATP-EQP	ATP	ATP-EQP	ATP	ATP-EQP
α	10.578***	0.017	12.335***	1.960***	12.567***	2.198***
(t-value)	(31.78)	(0.04)	(31.55)	(4.67)	(26.04)	(3.75)
Wald test	1.61	0.00	11.66	21.78	10.54	14.03
(P-value)	(0.209)	(0.970)	(0.001)	(0.000)	(0.002)	(0.000)
SE	0.333	0.445	0.391	0.420	0.483	0.587
R^2	0.971	0.449	0.975	0.736	0.955	0.488

Note: *Significant at 10% level, **Significant at 5% level, ***Significant at 1% level. ATP, average trading price.

however, converges from above even though the supply curve is less elastic than the demand curve. In this respect, our results appear to contradict the results of Smith (1962), but we do not believe that this is the case for the following reason. In our experiment, the trading numbers are relatively small in the first few periods. Thus, sellers supply fewer quotas compared with the normal situation. As a result, the quota prices are high in the first few periods and converge to the quota price in the SPNE from above. Figure 5 indicates that the number of trades increases over time.[14] The other possibility is that subjects tend to start the experiment by investing in large-sized vessels and that they then adapt their investment by reducing the size of their vessels when necessary.[15]

Third, the results shown in Table 4 indicate that the initial allocation may affect the market outcome: the quota prices converge to higher prices in the A1 and A2 series than in the basic series. The persistent difference in the quota price of permits is statistically confirmed by the Mann–Whitney test with the null hypothesis that the probability distributions of the quota price are identical across treatments. This result indicates that the difference between the basic series and the other series is statistically significant, as shown in Table 5. The influence of the initial allocation has been observed in

[14] In the real world, when the government tries to establish a comprehensive ITQ program, small-scale fishers should be included because the number of small-scale fishers is sometimes very large. However, small-scale fishers are often not used to market transactions because they are traditional fishers in small local communities. They may also be reluctant to sell quotas because they assume that they should keep quotas to maintain the tradition of their communities. Because they are potential sellers of quotas, the numbers of trades may be relatively small at the beginning of ITQ programs. Our results show that in such cases, the quota prices may be relatively high in the beginning period and that they may converge to the EQP from above. Several studies have considered the problem of the thinness of quota markets. For example, Tisdell (2011) compares the performance of double auctions with that of call auctions: a possible reason for lower quota prices in a double auction mechanism is that the markets in the double auction experiment were thin.

[15] We will refer to this point in Subsection 4.2. The estimation of choices of vessels demonstrates that there is a trend in which the number of large-sized vessels decreases over time.

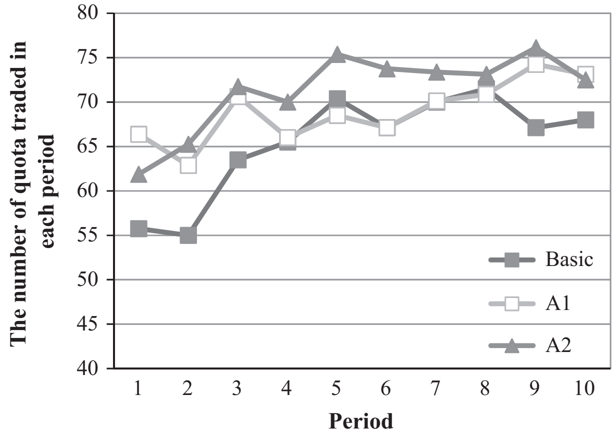

Figure 5 The number of quota traded in each period.

Table 5 The result of Mann–Whitney test on the quota price in each treatment

	A1	A2
Base	−2.721***	−2.873***

Note: *Indicates significant at 10% level, **indicates significant at 5% level, and ***indicates significant at 1% level.

the literature. For example, Murphy and Stranlund (2006) demonstrate that a change in the method of initial allocation affects who are net sellers and who are net buyers and, accordingly, what the quota prices are. Having observed this result, they suggest that the endowment effect may influence subjects' behaviour. Other articles also find that the method of initial allocation affects subjects' behaviour (for example, see Wråke *et al*. 2002). This type of effect has been taken into consideration in a number of experimental settings (for example, see Kahneman *et al*. 1991). Our results also suggest that the initial allocation can influence quota trading.

One possible reason for the difference between the basic series and the other series is that it takes longer for subjects to determine the EQP in the additional series than in the basic series. For example, consider the A1 series in which subjects with six initially allocated quotas choose *Large* and subjects with 10 initially allocated quotas choose *Small*. Subjects who choose *Large* catch more fish than those who choose *Small*. Therefore, the amount of quota trades becomes large. However, in the case in which subjects with 10 initially allocated quotas choose *Large* and subjects with six initially allocated quotas choose *Small*, the amount of quota trades becomes small. This small number of quota trades occurs because the subjects do not need to make many deals to achieve the optimal catch for their own vessels. If the former case takes place more frequently than the latter case, the quota price may be high. Moreover, depending on which case arises, the amounts of quota trades may vary drastically over time. Therefore, the quota prices become unstable, and it takes longer for the quota price to converge to the EQP in the additional series than in the basic series. The variance of the trading price without outliers is shown in Table 6. The variance in the A1 and A2 series is clearly greater than that in the basic series. Moreover, relatively large variance remains in the last few periods in the additional series.

4.2. Choice of vessels

We now examine whether quota prices influence choice of vessel size. We estimate the following equation with a random effects probit model. Our estimation is based on the panel data of all series. The dependent variable is the choice of a large-sized vessel (*Large* = 1, *Small* = 0).

$$\begin{aligned} Invest_{i,t} = {} & c + \gamma_1 MarketIndex_{t-1} + \gamma_2 TPV_{t-1} + \gamma_3 LARGE_{t-1} + \gamma_4 AL \\ & - dummy_{6,i} + \gamma_5 AL - dummy_{10,i} + \gamma_6 AL - dummy_{5,i} + \gamma_7 AL \\ & - dummy_{11,i} + \gamma_8 INVEST_{i,t-1} + \gamma_9 PROFIT_{i,t-1} \\ & + \gamma_{10} PERIOD_t + \mu_i + \varepsilon \end{aligned} \tag{8}$$

$Market\ Index_{t-1}$: variables that are types of signals from the quota market in period $t-1$: ATP and the gap between the maximum profit of *Large* and that of *Small* given the ATP.

TPV_{t-1}: the variance of the trading price in period $t-1$.

$LARGE_{t-1}$: the number of subjects who chose *Large* in period $t-1$.

$AL - dummy_{6,i}$: low allocation dummy, which is equal to one when subject i is given six coupons in the A1 series.

$AL - dummy_{10,i}$: high allocation dummy, which is equal to one when subject i is given 10 coupons in the A1 series.

$AL - dummy_{5,i}$: low allocation dummy, which is equal to one when subject i is given five coupons in the A2 series.

Table 6 The variances of trading prices

Period	Basic	A1	A2
1	28.764	67.921	39.061
2	60.716	63.940	39.342
3	35.321	63.983	52.979
4	34.645	43.614	42.032
5	25.862	53.088	43.365
6	24.457	25.352	40.140
7	11.015	23.405	31.223
8	9.371	20.594	29.867
9	10.126	21.974	23.483
10	12.499	16.122	23.469
Average	25.278	39.999	36.496

$AL - dummy_{11,i}$: high allocation dummy, which is equal to one when subject i is given 11 coupons in the A2 series.
$INVEST_{i,t-1}$: subject i chooses *Large* in period $t - 1$.
$PROFIT_{i,t-1}$: the profit of subject i in period $t - 1$.
$PERIOD_t$: period t.
μ_i: this term is the unobserved, panel-level random effect.
ε: error term.

The subjects are assumed to choose their own vessel types to maximise their own profits. We choose two variables as the *Market Index*. Based on each of these variables, the subjects may compare the profit from choosing a large-sized vessel with that of choosing a small-sized vessel. The first variable is ATP in the previous period. Higher expected quota prices render it less attractive to be a potential buyer of quotas in the quota market. Therefore, the coefficient of the ATP in the previous period is expected to be negative. The second variable is the gap in maximum profits: the maximum profit when choosing *Large* minus that when choosing *Small*, which is calculated based on the ATP in the previous period. The coefficient of the gap of profits is expected to be positive.

The variance of the trading price in the previous period may affect subjects' choice of vessel size. The sign of the coefficient may be either positive or negative, depending on the risk preferences of subjects. Because the purpose of this paper is not to examine risk preferences, we adopt this variable to obtain clearer results for the independent variables that are important in this study.

The number of subjects who chose *Large* in the previous period may influence the choice of vessel types. That is, a greater number of subjects who chose *Large* in the previous period render it more likely that each subject chooses *Small*. Therefore, the sign of the coefficient of *LARGE* is expected to be negative.

We also choose three types of variables that are specific to each subject. First, as noted in Subsection 3.1, the method of initial allocation may affect the choice of vessel. In this case, a larger amount of initially allocated quotas renders it more likely for each subject to choose *Large*. Regarding the allocation dummies, AL-dummy6 and AL-dummy5 are low allocation dummy variables, while AL-dummy10 and AL-dummy11 are high allocation dummy variables. Therefore, the coefficients of AL-dummy6 and AL-dummy5 are expected to be negative, whereas the coefficients of AL-dummy10 and AL-dummy11 are expected to be positive. The other two independent variables are the choice of *Large* for subject i and the profit of subject i in the previous period. The former variable is considered to positively affect the choice of *Large* because of a type of *law of inertia*. That is, a subject becomes used to trading quotas with the vessel type that he/she chose in previous periods. However, the coefficient of the latter variable may be either positive or negative. When a subject succeeds in earning large profits in the previous period, he/she may choose *Large* because of perception that *Large* will earn greater profits than *Small*.

Finally, we include *PERIOD* in our estimation equation, because a time trend variable captures effects that are not explained by other independent variables. Moreover, if the coefficient of this variable is significantly negative, it implies that the number of large-sized vessels is large in the beginning period. Thus, a significantly negative coefficient for this variable may explain the result that the price converges to the EQP from above.

A summary of the results is shown in Table 7. With regard to the ATP and the number of subjects who chose *Large* in the previous period, we obtain the expected results. The results show that subjects chose their vessels according to their expected profits.

However, with regard to the effect of the initial allocation, the results of the A2 series are as expected, whereas those of the A1 series are not significant. In the A1 series, the difference in allocation among the subjects is not very large. Therefore, the effect of unequal allocation is not significant. However, the initial allocation in the A2 series is clearly unequal compared with that in the basic series. Therefore, the initial allocation influences the choice of vessels, as theoretically expected.

Table 7 also shows the calculation of marginal effects based on our estimation. In this table, the market index shows a steady effect for decision making: an increase in the ATP by one increases the probability of selecting *Large* by 1.1 per cent. However, the marginal effects of AL-dummy 5 and AL-dummy 11 show the large impact of the initial allocation on the choice of vessel size. Compared with the case of equal allocation (the basic sessions), 11 initial-quota allocation increases the probability of selecting *Large* by 14.2 per cent.

Table 7 The factor analysis about choice of large-sized vessels

Independent variables	Market index			
	ATP	ATP (marginal effect)	Gap of profit	Gap of profit (marginal effect)
Market index	−0.029* (−1.89)	−0.011*	−0.000 (−0.16)	−0.000
TPV	0.002* (1.70)	0.001*	0.001 (0.69)	0.000
LARGE	−0.035 (−1.62)	−0.013	−0.036* (−1.66)	−0.014*
AL-dummy 6	0.149 (0.81)	0.060	0.076 (0.41)	0.029
AL-dummy 10	0.124 (0.67)	0.046	0.049 (0.26)	0.018
AL-dummy 5	−0.318* (−1.75)	−0.124*	−0.365** (−2.00)	−0.142**
AL-dummy 11	0.394** (2.14)	0.142**	0.348* (1.88)	0.127*
INVEST	0.296*** (3.89)	0.113***	0.290*** (3.82)	0.111***
PROFIT	0.000 (0.71)	0.000	0.000 (0.71)	0.000
Period	−0.031** (−2.45)	−0.012**	−0.023* (−1.74)	−0.009*
c	0.785*** (2.89)	—	0.450** (2.13)	—

Note: 2592. Dependent variable: choice of large. *Significant at 10% level, **Significant at 5% level, ***Significant at 1% level. ATP, average trading price. Values in parentheses are *t*-values.

Result 2: (a) A lower ATP in the previous period, (b) fewer large-sized vessels in the previous period, and (c) a larger amount of initially allocated quotas render it more likely for subjects to choose large-sized vessels.

We also find the following interesting result. If the price expectations of subjects are formed according to the trading prices in past periods, the price in the first period (or in the first few periods) may affect the trading prices in ensuing periods. Figure 6 indicates that the ATP in the first period negatively influences the number of subjects who choose *Large* in the ensuing periods in the basic series. However, we observe no clear correlation of this type in the A1 series. In addition, in the A2 series, the quota price in the first period moderately influences the choice of vessel in ensuing periods: the correlation coefficient is −0.29.

Result 3: The ATP in the first period clearly influences the vessel sizes in ensuing periods in the basic series.

This result implies that the trading prices at the starting point of an ITQ market are very important for achieving efficiency of the vessel sizes. Because the correlation between ATP and $ATP - EQP$ is strong, it may be concluded that the deviation in trading prices from the EQP in the first period delays the convergence of vessel sizes to those in the SPNE.

5. Concluding remarks

This paper used a laboratory experiment to examine the effect of ITQ markets on fishers' choice of vessel size. Our results have several important implications.

First, we found that the ATP converges to the theoretical EQP, given the numbers of both types of vessels. Subjects adjust to the market, and the quota

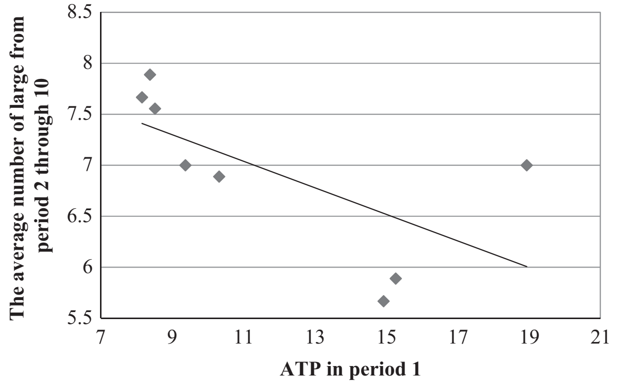

Figure 6 The effect of average trading price in period 1 on Large Vessels in the ensuring periods in the basic series.

price converges to the EQP conditioned on the vessel sizes even if the vessel sizes change over time.

Second, we found that subjects choose their own vessels to maximise their profits based on the quota trading prices in the previous period. For example, a lower average ATP in the previous period renders it more likely that subjects will choose a large-sized vessel. This relationship exists because a large-sized vessel owner is a buyer of quotas in the quota market and thus benefits from a decrease in the quota price. This result also implies that the efficiency of quota markets in ITQ programs in the beginning period is important because any inefficiency in the quota markets may affect vessel sizes in ensuing periods, which, in turn, may lead to inefficient vessel sizes. Given the model setup and experimental design, the first two results are particularly important when considering the long-run equilibration.

Third, theoretically, the initial allocations do not matter in terms of the efficiency of ITQ markets when the numbers of both large- and small-sized vessels are fixed and when the quota market is perfectly competitive. However, the initial allocation may significantly influence vessel sizes through two channels: first, a higher initial allocation to a subject increases the likelihood that the subject invests in a large-sized vessel; second, the quota price may be higher and more unstable under unequal allocation than under equal allocation; thus, whether the allocation is equal influences subjects' choice of vessel type.

Finally, achieving efficient vessel sizes is an important task for the management of fisheries, although regulatory authorities, seeking political benefits, often allow fishers to use inefficient-sized vessels. ITQ regimes may increase the efficiency of vessel sizes. Because fishers respond to quota prices in selecting vessel sizes, some incentive schemes (e.g. subsidies) with an ITQ regime may be used to eliminate this inefficiency. However, the results show that the proper functioning of the quota market plays a key role for both short- and long-run efficiencies, in which the total social cost for catching fish is minimised.

Nevertheless, other factors affecting the functioning of ITQ regimes require additional research. For example, uncertainty in fish prices and costs may also play an important role in determining the degree of efficiency under an ITQ regime. Exit from the fishing industry is also a crucial topic. Moreover, sticky capital is an important issue. If vessel size decisions are less flexible in the real world than in the experiment in this paper, investments based on erroneous signals could have a lasting impact on efficiency. Future research may clarify the effects of these factors by using laboratory experiments.

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