

Efficiency of Individual Transferable Quotas (ITQ) Systems and Input and Stock Controls

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Abstract

This paper examines whether or not the number of fishers is optimal under an Individual Transferable Quotas (ITQ) program. We consider two case on the structure of the quota market: the case in which all fishers are price takers, and the case in which large-scale fishers have market power. When all fishers are price takers in the quota market, the social optimum is likely to be achieved given TAC level. On the other hand, when low-cost fishers have market power in the quota market, the inefficiency may be serious: excess entry of low-cost fishers and insufficient exit of high-cost fishers may take place. Moreover, we demonstrate that vessel controls and stock targeting may work for an ITQ program.

Key Words: Individual transferable quotas, market power, fishery management.

JEL Classification: Q22, Q28.

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1. Introduction

The depletion of marine resources has been serious for the past few decades in many countries. In response to those situations, governments set several types of regulations on open access fisheries. First, they used input controls, such as vessel control, regulations on fishing gears, and the setting of fishing seasons. However, these measures often give fishers unexpected incentives to over-invest in equipment. As a result, output controls have drawn attention since the late 1970s.¹ In particular, the setting of Total Allowable Catch (TAC) with an Individual Transferable Quota (ITQ) system is considered to be effective for reducing overcapacity, and accordingly, accomplishing the efficiency of fishing activities. Under an ITQ system, an inefficient fisher gains more from selling quotas which 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.

Some countries have introduced ITQ systems in the late 1970s and the 1980s. For example, the government of Iceland introduced this system for the herring fisheries in 1976, for the capelin fishery in 1980, and for the demersal fisheries in 1984.² Other countries, such as New Zealand, Australia, and Norway, have introduced ITQ systems. Many empirical studies assessed the effect of ITQs on efficiency and the conservation of resources (See Clark et al. (1988), Arnason (1993), Gauvin et al. (1994), Squires and Kirkley (1996), Adelaja et al. (1998), Weinger (1998) among them). In general, those studies concluded that overcapacity was reduced, and accordingly there have been efficiency gains, although the accomplishment of restructuring takes time. Moreover, the scales of efficiency gains were sometimes smaller than expected.

Theoretically, several studies found that there are some factors that hinder ITQ systems from accomplishing the efficiency completely. Anderson (1991) demonstrated that the total

¹ For the survey of regulations, see Clark (2006).

² See Arnason (1993) for the evaluation of these ITQ systems in Iceland.

cost is not minimized to harvest a certain amount of fish when some fishers have market power in the quota market. This is because fishers take into consideration a change in the price of quotas due to changes in their own purchasing behavior. In such a case, they buy fewer quotas at a lower price. Thus, inefficiency is not completely removed. Bergland and Pederson (2006) considered the case in which some fishers are risk averters, and proved that fishers buy fewer quotas when they are risk averters than when they are risk neutral.³

The purpose of this paper is to examine theoretically whether a TAC-ITQ system is able to achieve efficiency. “Efficiency” implies the minimization of the total harvesting cost (the sum of the total cost of all existing fishers) for and/or the maximization of the sum of all fishers’ profits from catching a certain amount of fish. In particular, we consider two cases on the structure of the quota market: the case in which all fishers are price takers, and the case in which some fishers with low-cost vessels have market power in the quota market. Since it is possible that a few large-scale fishers hold a large part of quotas, it may be that those large-sale fishers have market power. In such a case, the quota market does not function well in terms of efficiency. Anderson (1991) demonstrated this point given number of large-scale fishers. Therefore, it is important to consider both cases.⁴

There are three key features. First, contrast to Anderson (1991), we consider the determination of the number of fishers. In the real world, from the viewpoint of a government, it is important to give inefficient fishers incentives to quit fishing. And it is often said that a TAC-ITQ system can realize this process. To this end, we consider two types of fishers: efficient low-cost fishers and inefficient high-cost fishers. Then, we compare the equilibrium numbers of both types of fishers with the numbers when the total

³ On the other hand, Danielsson (2000) proved that an ITQ system could generate a first-best solution even if production externalities exist. Moreover, Boyce (2004) examined the choice of regulating instruments, and obtained the reasons why inefficient regulations are adopted in terms of political economy.

⁴ See Anderson (1991) for this point. Matulich and Sever (1999) also referred to market power. They, however, focused on the relationship between fishers and processing industries.

harvesting cost is minimized.

Second, we take into consideration fixed costs. Vestergaard (2005) theoretically demonstrated that the existing of sunk costs delays the restructuring of fishing industry under a TAC-ITQ system. By contrast, although fixed costs play an important role in our analysis, our focus is whether market power hinders ITQ systems from accomplishing efficiency.

Third, it may be that some additional measures complement TAC-ITQ systems in terms of efficiency. For example, it is possible that vessel control contribute to an ITQ to function well. In reality, although input controls were adopted by governments, it is often considered that those measures were not able to achieve the goal of resource management. In this paper, we examine whether input and stock controls are able to complement TAC-ITQ systems.

Main results are as follows. When all fishers are price takers in the quota market, the social optimum is likely to be achieved given TAC level. One factor of inefficiency is that the number of transactions between low-cost and high-cost fishers is too large, and that the number of high-cost fishers is too small. On the other hand, when low-cost fishers have market power in the quota market, the inefficiency may be more serious: excess entry of low-cost fishers and insufficient exit of high-cost fishers may take place. Moreover, we demonstrate that vessel controls and stock targeting may work for a TAC-ITQ system.

The structure of this paper is as follows. Section 2 describes the basic model. Section 3 describes the social optimum. Section 4 investigates the harvesting structures in the case in which all fishers are price takers in the quota market, whereas Section 5 focuses on the case in which efficient low-cost fishers have market power. Section 6 refers to vessel and stock controls. Section 7 provides concluding remarks.

2. The Model

Consider a fishery in which n_L low-cost fishers, which are fishers with low-cost vessels, and n_S high-cost fishers, which are fishers with high-cost vessels. They are harvesting fish

stock of single species. All low-cost fishers/vessels are identical, and all high-cost fishers/vessels are also 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 vessels. The government sets a Total Allowable Catch (TAC) and introduces an Individual Transferable Quotas (ITQs) system for the fishing area. Before the introduction of the TAC-ITQ system, there are too many high-cost fishers in terms of efficiency. “Efficiency” implies the minimization of the total harvesting cost (the sum of the total cost of all existing fishers) for and/or the maximization of the sum of all fishers’ profits from catching a certain amount of fish.

The cost structures of both types of fishers are:

$$C_L(q_L) = c_L \left(\frac{q_L}{X} \right) + F_L, \quad C_S(q_S) = c_S \left(\frac{q_S}{X} \right) + F_S, \quad c'_i > 0, \quad c''_i > 0, \quad (1)$$

where q_i , c_i , and F_i denote the amount of catch, the variable cost, and the fixed cost of a fisher of type i ($i = L, S$), respectively. The variable X denotes the fish population biomass stock, which affects the variable costs of both types of fishers: the larger is the stock, the lower is the variable cost to catch a certain amount of fish.⁵ Then, when the government sets a TAC, which is denoted by \bar{Q} , the total harvesting cost for the society (TC) is:

$$TC = \sum_{j=1}^{n_L} \left\{ c_L \left(\frac{q_{L,j}}{X} \right) + F_L \right\} + \sum_{k=1}^{n_S} \left\{ c_S \left(\frac{q_{S,k}}{X} \right) + F_S \right\}, \quad (2)$$

where $\sum q_{L,j} + \sum q_{S,k} = \bar{Q}$. It is assumed that $F_L > F_S$. 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 ($i = L, S$). We assume that a low-cost

⁵ In the literature of the analyses of fishery economics, this variable is combined with the variable which represents the fishing effort, when the effort is explicitly described. In this paper, the variable X has the same meaning as in those analyses in that an increase in the biomass lowers the variable cost to catch a certain amount of fish. The cost structure in this paper is similar to that used in Danielsson (2000).

fisher is more efficient than a high-cost fisher, which means that:⁶

$$AC_L(\hat{q}_L) < AC_S(\hat{q}_S), \quad \hat{q}_L > \hat{q}_S. \quad (3)$$

The demand curve for fish is downward sloping:

$$p = P(\bar{Q}), \quad P' < 0. \quad (4)$$

Unless the government changes the TAC level, the price of fish does not change. Moreover, for simplicity, we do not consider cohorts. This implies that the quality of fish does not change due to a change in the TAC level.

We consider two step determination of harvesting structure. In the first stage, the numbers of both types of vessels/fishers are determined. In other words, vessels are transacted between fishers. Therefore, we call this process as the vessel adjustment stage. We divide this stage into three processes: the shift from high-cost vessels to low-cost vessels, the exit of high-cost vessels/fishers, and the entry of low-cost vessels/fishers. The first process is important since it is sometimes difficult for potential fishers to enter this industry. In such a case, whether or not incumbent high-cost fishers improve their productivity is crucial for the efficiency of a TAC-ITQ system, and accordingly, efficient resource management. The second process is also important since it is usual that there exist too many high-cost and small scale fishers. Therefore, whether or not and how the number of high-cost fishers can be decreased have been focused on in many countries. The third one may seem to be less realistic as compared with the first two processes, since new entry is not observed frequently. However, it is important to investigate whether or not free entry of low-cost (efficient) fishers achieves the objective of a TAC-ITQ system. If fishing activities make big profits, it is possible that firms enter into this industry.

Since it is assumed that there are too many high-cost fishers in the beginning, we do not consider new entry of high-cost vessels, and the shift from low-cost to high-cost vessels. In

⁶ We set these assumptions in terms of real situations, although we may be able to find counter examples. Theoretically, the opposite cases can be analyzed in a similar way.

the second stage, the quotas are transacted between fishers. In this stage, each fisher does not sell all quotas s/he holds. We solve the determination of the harvesting structure by backward induction.

In terms of real situations faced by fishers and governments in charge of fish resource management, we assume that low-cost fishers are always buyers of vessels and quotas, whereas high-cost fishers are always sellers of vessels and quotas. Moreover, we exclude the case in which a fisher does not use part of her/his quotas to manipulate the price of quota.

3. Social Optimum

First, we examine the social optimum to catch a certain amount of fish which is regulated by TAC. Since the fish price is constant, the objective is to minimize the total harvesting cost,

(2). Rewrite the total cost function as follows:

$$TC = \sum_{j=1}^{n_L} \left\{ c_L \left(\frac{q_{L,j}}{X} \right) + F_L \right\} + \sum_{k \neq l} \left\{ c_S \left(\frac{q_{S,k}}{X} \right) + F_S \right\} + \left(c_{s,l} \left(\frac{\bar{Q} - \sum q_{L,j} - \sum q_{S,-l}}{X} \right) + F_S \right). \quad (2)'$$

Differentiation of (2)' with respect to $q_{L,j}$ and $q_{S,k}$ yields the following first order conditions (FOCs):

$$c'_{L,j} = c'_{S,l}, \quad c'_{S,k} = c'_{S,l}. \quad (5)$$

Thus, the total harvesting cost can be rewritten again as follows:

$$TC = n_L \left\{ c_L \left(\frac{q_L}{X} \right) + F_L \right\} + n_S \left\{ c_S \left(\frac{q_S}{X} \right) + F_S \right\}. \quad (2)''$$

Using (5), total differentiation of the total cost function with respect to n_i ($i = L, S$) yields:

$$\frac{dTC}{dn_L} = c_L \left(\frac{q_L}{X} \right) + F_L - c'_S \cdot q_L \cdot \frac{1}{X} = 0, \quad (6)$$

$$\frac{dTC}{dn_S} = c_S \left(\frac{q_S}{X} \right) + F_S - c'_L \cdot q_S \cdot \frac{1}{X} = 0. \quad (7)$$

Since $c'_s = c'_L$ holds, it is clear that each condition implies that the average cost is equal to the marginal cost for each type of fisher. From (3), it is impossible that (6) and (7) are satisfied at the same time. From (3), the following proposition holds.

Proposition 1: *At the social optimum, high-cost fishers exit from this fishery, and each low-cost fisher which engages in fishing catches \hat{q}_L .*

4. Harvesting Structure when Both Types are Price takers

4.1 Equilibrium in the Second Stage

Assume that both types of fishers are price takers. In the second stage, each type of fisher determines the amount of quota which s/he buys (or sells) so that her/his profit is maximized given the price of quota. The profit functions are given by:

$$\pi_{L,j} = p(\bar{Q})q_{L,j} - C_L\left(\frac{q_{L,j}}{X}\right) - r \cdot (q_{L,j} - \bar{q}_{L,j}), \quad (8)$$

$$\pi_{S,k} = p(\bar{Q})q_{S,k} - C_S\left(\frac{q_{S,k}}{X}\right) - r \cdot (q_{S,k} - \bar{q}_{S,k}), \quad (9)$$

where r , $\bar{q}_{L,j}$, and $\bar{q}_{S,k}$ denote the price of quota, the initial allocation for each low-cost fisher, and the initial allocation for each high-cost fisher, respectively. For simplicity, without any transactions of vessels, all low-cost fishers have the same amount of initial allocation, $\bar{q}_{L,j} = \bar{q}_L$, and all high-cost fishers also have the same amount of initial allocation, $\bar{q}_{S,k} = \bar{q}_S$. The FOCs are:

$$p(\bar{Q}) - c'_L \cdot \frac{1}{X} - r = 0, \quad p(\bar{Q}) - c'_S \cdot \frac{1}{X} - r = 0. \quad (10)$$

Thus, given number of each type of fisher, each low-cost (resp. high-cost) fisher harvests

q_L^T (resp. q_S^T), and in equilibrium, the following conditions hold:

$$c'_L \left(\frac{q_L^T}{X} \right) = c'_S \left(\frac{q_S^T}{X} \right), \quad (11)$$

$$n_L q_L^T + n_S q_S^T = \bar{Q}, \quad \text{or} \quad q_S^T = \frac{\bar{Q} - n_L q_L^T}{n_S} \quad (12)$$

It should be noted that, since all fishers are price takers, their behavior in the quota market is not influenced by initial allocation.

Total differentiation of (8) and (9) with respect to n_i ($i = L, S$) yields:

$$\begin{pmatrix} c''_L/X & -c''_S/X \\ n_L & n_S \end{pmatrix} \begin{pmatrix} dq_L^T/dn_i \\ dq_S^T/dn_i \end{pmatrix} = \begin{pmatrix} 0 \\ -q_i^T \end{pmatrix}.$$

Thus, we obtain:

$$\frac{dq_L}{dn_L} = -\frac{c''_S q_L}{\Omega_1}, \quad \frac{dq_S}{dn_L} = -\frac{c''_L q_L}{\Omega_1}, \quad \frac{dq_L}{dn_S} = -\frac{c''_S q_S}{\Omega_1}, \quad \frac{dq_S}{dn_S} = -\frac{c''_L q_S}{\Omega_1}, \quad (13)$$

where $\Omega_1 = (c''_L n_S + c''_S n_L) > 0$. Note that all of them are negative.

Substituting (12) into (2)", and using (11) and (13), the FOCs for the minimization of the total harvesting cost are the same as (6) and (7). Using (13), from (6) and (7), the following conditions hold:

$$\begin{aligned} \frac{d^2 TC}{dn_L^2} &= -c''_S \cdot \frac{1}{X} \cdot \frac{dq_L^T}{dn_L} > 0, & \frac{d^2 TC}{dn_S^2} &= -c''_L \cdot \frac{1}{X} \cdot \frac{dq_S^T}{dn_S} > 0, \\ \frac{d^2 TC}{dn_L dn_S} &> 0, & \frac{d^2 TC}{dn_L^2} \cdot \frac{d^2 TC}{dn_S^2} - \left(\frac{d^2 TC}{dn_L dn_S} \right)^2 &= 0. \end{aligned} \quad (14)$$

From the last condition of (14), it is clear that the second order condition (SOC) for an interior solution is not satisfied. Thus, the corner solution holds: all fishers are low-cost, or all fishers are high-cost. Since a low-cost fisher is assumed to be more efficient than a high-cost fisher, the following proposition holds.

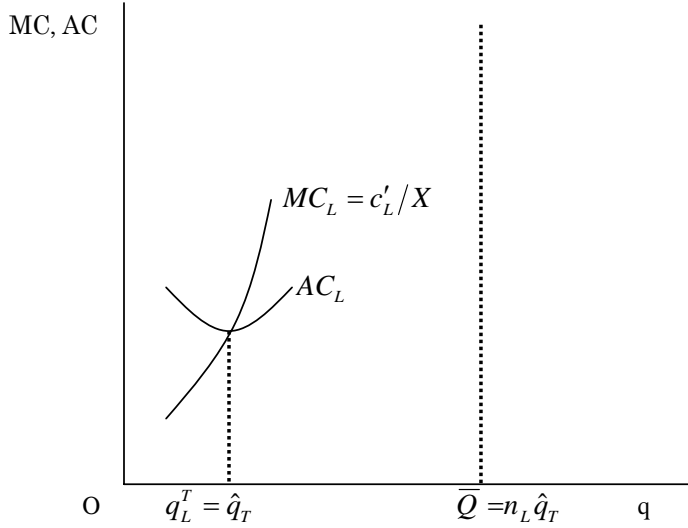


Figure 1. The situation in the second stage.

Proposition 2: *Suppose that both types of fishers are price takers in the quota market (in the second stage). Then, if the numbers of both types of fishers are adjusted so that the total harvest cost is minimized given the structure of the quota market, the social optimum is achieved.*

Figure 1 shows the situation in the second stage.

4.2 Shifts of Vessel Scales

First, in this subsection, we consider the changes in vessel scales from high-cost to low-cost vessels given the total number of vessels/fishers, and discuss whether the social optimum is achieved. Let \bar{n} denote the total number of vessels/fishers, that is $\bar{n} = n_L + n_S$. For simplicity, it is assumed that the numbers of vessels can be determined continuously.

In the first stage, if $\pi_L > \pi_S$ holds, each high-cost fisher has an incentive to change her/his vessel from the high-cost to the low-cost one. Thus, when each fisher can determine the type of vessel to maximize her/his profit, $\pi_L = \pi_S$ holds in equilibrium.

In terms of social welfare, the total cost minimization is equivalent to the total profit

maximization, since the price of fish, and accordingly the consumer's surplus are constant under a certain level of TAC. The total profit is described as follows:

$$\Pi = n_s \pi_s + (\bar{n} - n_s) \pi_L. \quad (15)$$

Total differentiation of (15) with respect to n_s yields

$$\begin{aligned} \frac{d\Pi}{dn_s} = & \pi_s - \pi_L + n_s \cdot \left(p(\bar{Q}) - c'_s \cdot \frac{1}{X} - r \right) \cdot \frac{dq_s^T}{dn_s} + (\bar{n} - n_s) \cdot \left(p(\bar{Q}) - c'_L \cdot \frac{1}{X} - r \right) \cdot \frac{dq_L^T}{dn_s} \\ & - \left(n_s \cdot (q_s^T - \bar{q}_s) + (\bar{n} - n_s) \cdot (q_L^T - \bar{q}_L) \right) \cdot \frac{dr}{dn_s} + r \cdot \left(\frac{d\bar{Q}_s}{dn_s} + \frac{d\bar{Q}_L}{dn_s} \right), \end{aligned} \quad (16)$$

where \bar{Q}_i ($i = L, S$) denotes the total initial allocation for each type of fishers. Note that, in this case, a decrease in one high-cost vessel implies an increase in one low-cost vessel. Then, the fisher, who originally has a high-cost vessel and changes her/his vessel to the low-cost one, holds the initial allocation, \bar{q}_s . Since the fisher shifts her/his vessel from the high-cost to the low-cost, \bar{Q}_i changes due to the shift of vessel. This effect is represented by the last term of (16).

The total demand for and the total supply of quotas are equal in the second stage, and $d\bar{Q}_s/dn_s + d\bar{Q}_L/dn_s = 0$ since the TAC is constant. Therefore, from (10), the FOC for the maximization of the total profit is obtained:

$$\frac{d\Pi}{dn_s} = \pi_s - \pi_L = 0 \quad (17)$$

This condition is the same as the equilibrium condition when each fisher can determine the type of vessel to maximize her/his profit.

Proposition 3: *Suppose that the total number of vessels/fishers is constant, and that both types of fishers are price takers in the quota market (in the second stage). Then, when each fisher can determine the type of vessel to maximize her/his profit, the numbers of both types of fishers realized in equilibrium maximizes the total profit.*

4.3 The Exit of High-cost Inefficient vessels/fishers

Next, we consider the second process of the determination of the numbers of both types of vessels: the exit of high-cost inefficient vessels/fishers given the number of low-cost efficient vessels/fishers. The exit of a high-cost fisher implies that a low-cost fisher buys all of quotas which the high-cost fisher holds, and induces the high-cost fisher to give up fishing. Since a high-cost fisher obtains π_s^T by engaging in fishing activities, the price of “buying a high-cost vessel” for a low-cost fisher is equal to π_s^T .

From (10), a change in the profit of a low-cost fisher by buying a high-cost vessel is given by:

$$-\frac{d\pi_L}{dn_s} = (q_L^T - \bar{q}_L) \frac{dr}{dn_s} - \frac{d\bar{q}_L}{dn_s} \cdot r - \pi_s^T. \quad (18)$$

Note that $d\bar{q}_L/dn_s = -\bar{q}_s$. On the other hand, since the total demand for and the total supply of quotas are equal in the second stage, the effect of this transaction process on the social welfare is given by:

$$-\frac{d\Pi}{dn_s} = \bar{q}_s \cdot r - \pi_s^T. \quad (19)$$

Since high-cost fishers are assumed to be sellers of quotas in the second stage, this implies that per unit profit of a high-cost fisher is equal to r when the total profit is maximized. In this case, from (10), the average cost is equal to the marginal cost for high-cost fishers. Therefore, this is the same as the condition for the total cost minimization ((7)), given the number of low-cost fishers.

From (18) and (19), the evaluation of $-d\pi_L/dn_s$ at $d\Pi/dn_s = 0$ yields

$$-\frac{d\pi_L}{dn_s} \Big|_{d\Pi/dn_s=0} = (q_L^T - \bar{q}_L) \frac{dr}{dn_s} \quad (20)$$

From (10) and (13), it is obtained that:

$$\frac{dr}{dn_s} = \frac{c_L'' c_S'' q_S}{\Omega_1} > 0 \quad (21)$$

Since low cost fishers buy additional quotas in the second stage, (20) is positive.

Proposition 4: *Suppose that the number of low-cost fishers is constant, and that both types of fishers are price takers in the quota market (in the second stage). Then, the number of high-cost vessels is smaller when each low-cost fisher can determine how many “high-cost fishers” s/he buys than when the total profit is maximized.*

This implies that the excess transactions are realized between low-cost and high-cost fishers. The intuition is as follows. The exit of one high-cost fisher decreases the supply of quotas in the second stage. The amount of decrease is equal to $\bar{q}_s - q_s$. On the other hand, due to the exit, a low-cost fisher gains quotas the amount of which is equal to \bar{q}_s , which is also equal to the decrease in the demand for quotas in the second stage. Therefore, the price of the quota in the second stage decreases due to the exit of a high-cost fisher. Then, each low-cost fisher gains from the price decrease, whereas each existing high-cost fisher loses from it. The low-cost fisher who carries out a transaction with a high-cost fisher does not take into consideration the loss for existing high-cost fishers. Therefore, excess transactions are realized.

In this case, the high-cost fishers are excessively driven out from the fishery. However, Proposition 1 states that all high-cost fishers exit from the fishery at the social optimum. Therefore, in terms of exit of high cost fishers, the second process may work for the achievement of the goal of a TAC-ITQ system.

4.4 New Entry of Low-cost Fishers

Let us now turn to the third process: entry of low-cost fishers when the number of high-cost

fishers is given. Similar to the previous subsection, from (10), a change in the profit of an incumbent low-cost fisher when a new low-cost fisher enters is given by

$$\frac{d\pi_L}{dn_L} = -(q_L^T - \bar{q}_L) \frac{dr}{dn_L} < 0, \quad (22)$$

and that of an incumbent high-cost fisher is given by

$$\frac{d\pi_S}{dn_L} = -(q_S^T - \bar{q}_S) \frac{dr}{dn_L} > 0. \quad (23)$$

Thus, a change in the total profit is:

$$\frac{d\Pi}{dn_L} = \tilde{\pi}_L + n_L \frac{d\pi_L}{dn_L} + n_S \frac{d\pi_S}{dn_L} \quad (24)$$

where $\tilde{\pi}_L$ denotes the profit of an entrant, which is different from the profits of the incumbent low-cost fishers, since the entrant does not have any initial allocation of quotas.

From (6) and (10), it holds that, when $d\Pi/dn_L = 0$, the profit of low-cost fishers with positive (resp. zero) initial allocation of quotas is positive (resp. zero). Therefore, the following proposition holds.

Proposition 5: *Suppose that the number of high-cost fishers is constant, and that both types of fishers are price takers in the quota market (in the second stage). Then, when each potential low-cost fisher can determine whether or not to enter this fishery to maximize her/his profit, the numbers of both types of fishers realized in equilibrium maximizes the total profit.*

One point should be noted. In several points, ITQ has analogy to tradable emission permits on carbon dioxide (CO₂). In the case of ITQ, however, quotas for “outputs” are traded, whereas quotas for “inputs” are traded in the case of emission permits. Then, in the case of emission permits, free entry decreases the price of final products, and accordingly, improves the social welfare. On the other hand, in the case of ITQ, the output price does not change.

Therefore, free entry does not necessarily minimize (resp. maximize) the total cost (resp. the social welfare). This factor is quite different from emission trading on CO2.

5. Harvesting Structure when Low-cost Fishers Have Market Power

5.1 Equilibrium in the Second Stage

Consider the case in which high-cost fishers are price takers as in the previous section, whereas low-cost fishers have market power in the quota market. In the second stage, the first order condition for a high-cost fisher is the same as (10). Since all high-cost fishers catch the same amount, the FOC for a high-cost fisher can be rewritten as:

$$r = p(\bar{Q}) - c'_s \left(\frac{\bar{Q} - \sum q_{L,j}}{n_s X} \right) \cdot \frac{1}{X}. \quad (25)$$

Thus, the price of quota is the function of the amount of harvest by low-cost fishers, the fish population biomass, TAC, and the number of high-cost fishers: $r = r(\sum q_{L,j}, X, \bar{Q}, n_s)$.

Taking into consideration a change in the quota price, each low-cost fisher determines the amount of harvest so that her/his profit is maximized in a Cournot fashion. In this case, the profit function for each low-cost fisher j is given by

$$\pi_{L,j} = p(\bar{Q})q_{L,j} - C_L \left(\frac{q_{L,j}}{X} \right) - r(q_{L,j} + \sum q_{L,-j}, X, \bar{Q}, n_s) \cdot (q_{L,j} - \bar{q}_{L,j}) \quad (26)$$

Then, the FOC is given by:

$$\frac{\partial \pi_{L,j}}{\partial q_{L,j}} = p(\bar{Q}) - c'_L \cdot \frac{1}{X} - r - \frac{\partial r}{\partial q_{L,j}} \cdot (q_{L,j} - \bar{q}_{L,j}) = 0 \quad (27)$$

Let $q_{L,j}^M$ denote the equilibrium output of each low-cost fisher when s/he has the market power in the quota market. Then, from (10), the equilibrium output of each high-cost fisher is obtained: $q_s^M = (\bar{Q} - \sum q_{L,j}^M) / n_s$

Since $\partial r / \partial q_{L,j} > 0$ holds from (25), low-cost fishers buy fewer quotas than it would buy if they are price takers.⁷ The reason is that low-cost fishers have market power, and they are buyers in the quota market. Figure 2 shows the case in which the number of low-cost fisher is one. The residual supply curve indicates the TAC minus the total harvest by high-cost fishers for any given quota price. Since the low-cost fisher takes into consideration a change in the quota price, it buys q_L^M . If s/he is a price taker, it buys \tilde{q}_L .

It should be noted that the marginal costs of both types are not equal to each other in this case. Therefore, given the number of each type of vessels, the total harvesting cost is not minimized.

5.2 Shifts of Vessel Scales

Similar to Section 4, let \bar{n} denote the total number of vessels/fishers, that is $\bar{n} = n_L + n_S$. Suppose that \bar{n} is constant in this subsection. It is natural that if $\pi_L > \pi_S$ holds, each high-cost fisher has an incentive to change her/his vessel from the low-cost to the high-cost one. Thus, even if low-cost fishers have market power in the second stage, $\pi_L = \pi_S$ holds in equilibrium when each fisher can determine the type of vessel to maximize her/his profit.

For the total profit maximization problem, the similar condition as (16) holds:

$$\begin{aligned} \frac{d\Pi}{dn_S} &= \pi_S - \pi_L + n_S \cdot \left(p(\bar{Q}) - c'_S \cdot \frac{1}{X} - r \right) \cdot \frac{dq_S^M}{dn_S} + (\bar{n} - n_S) \cdot \sum \frac{\partial \pi_i}{\partial q_{L,i}} \cdot \frac{dq_{L,j}^M}{dn_S} \\ &\quad - \left(n_S \cdot (q_S^M - \bar{q}_S) + \sum (q_{L,j}^M - \bar{q}_{L,j}) \right) \cdot \frac{dr}{dn_S} + r \cdot \left(\frac{d\bar{Q}_S}{dn_S} + \frac{d\bar{Q}_L}{dn_S} \right) \quad (28) \\ &= \pi_S - \pi_L \\ &= 0 \end{aligned}$$

Thus, the following proposition holds.

⁷ Anderson (1991) showed this result when the number of low-cost fishers is one.

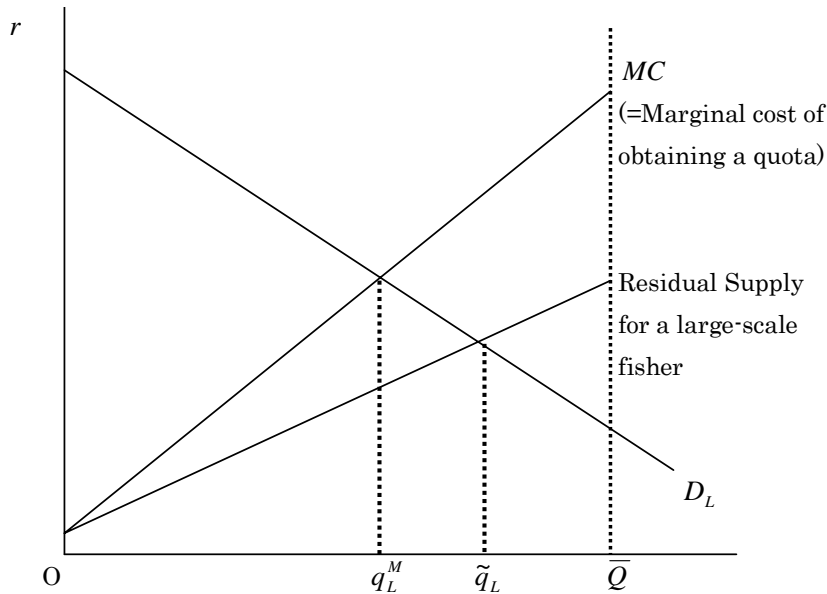


Fig.2 The quotas market when there is 1 large-scale fisher.

Proposition 5: *Suppose that the total number of vessels/fishers is constant, and that low-cost fishers have market power in the quota market (in the second stage). Then, when each fisher can determine the type of vessel to maximize her/his profit, the numbers of both types of fishers realized in equilibrium maximizes the total profit given the structure of the quota market.*

One point should be noted. Since the marginal costs of both types are not equal to each other in the quota market as noted above, the social optimum is not achieved in equilibrium. If the numbers of both types of vessels are ones at the social optimum, $\pi_L > \pi_S$ holds. Thus, in terms of efficiency, the number of low-cost fishers is too large.

5.3 The Exit of High-cost Inefficient Vessels/Fishers

On the second process, which is the exit of high-cost fishers given number of low-cost fishers, analogy to the case in which low-cost fishers are price takers holds. Thus, a change in the profit of a low-cost fisher by buying a high-cost vessel is given by:

$$-\frac{d\pi_{L,j}}{dn_s} = (q_{L,j}^M - \bar{q}_{L,j}) \frac{dr}{dn_s} - \frac{d\bar{q}_{L,j}}{dn_s} \cdot r - \pi_s^M \quad (29)$$

where π_s^M denotes the price of “buying a high-cost vessel. The effect of this transaction on the total profit is given by:

$$-\frac{d\Pi}{dn_s} = \bar{q}_s \cdot r - \pi_s^M \quad (30)$$

From (29) and (30), the evaluation of $-d\pi_L/dn_s$ at $d\Pi/dn_s = 0$ yields

$$-\left. \frac{d\pi_L}{dn_s} \right|_{d\Pi/dn_s=0} = (q_{L,j}^M - \bar{q}_L) \frac{dr}{dn_s} \quad (31)$$

However, in the present situation, it may hold that

$$\frac{dr}{dn_s} < 0.$$

To see this fact, consider the case of $n_L = 2$; that is, there exist firm 1 and firm 2.

Suppose that firm 1 buys one high-cost vessel. From (25),

$$\frac{dr}{dn_s} = \frac{c_s''}{n_s X} \cdot \left(q_s^M + \frac{dQ_L^M}{dn_s} \right)$$

holds. We assume that

$$\frac{\partial^2 \pi_{L,j}}{\partial q_{L,j}^2} = -c_{L,j}'' \cdot \frac{1}{X^2} - 2 \cdot \frac{\partial r}{\partial q_{L,j}} - \frac{\partial^2 r}{\partial q_{L,j}^2} \cdot (q_{L,j}^M - \bar{q}_{L,j}) < 0, \quad j = 1, 2 \quad (32)$$

where

$$\frac{\partial r}{\partial q_{L,j}} = \frac{\partial r}{\partial q_L} = \frac{c_s''}{n_s X^2} > 0, \quad \frac{\partial^2 r}{\partial q_{L,j}^2} = \frac{\partial^2 r}{\partial q_L^2} = -\frac{c_s'''}{n_s^2 X^3}. \quad (33)$$

It is also obtained from (27) that

$$\frac{\partial^2 \pi_{L,j}}{\partial q_{L,h} \partial q_{L,j}} = -\frac{\partial r}{\partial q_{L,h}} - \frac{\partial^2 r}{\partial q_{L,h} \partial q_{L,j}} (q_{L,j}^M - \bar{q}_{L,j}). \quad (34)$$

where

$$\frac{\partial^2 r}{\partial q_{L,h} \partial q_{L,j}} = \frac{\partial^2 r}{\partial q_L^2} = -\frac{c_s'''}{n_s^2 X^3}. \quad (35)$$

Moreover, it holds that

$$\frac{\partial^2 \pi_{L,1}}{\partial n_s \partial q_{L,1}} = -\frac{\partial r}{\partial n_s} - \frac{\partial^2 r}{\partial n_s \partial q_{L,1}} \cdot (q_{L,1}^M - \bar{q}_{L,1}) - \frac{\partial r}{\partial q_{L,1}} \cdot \bar{q}_s, \quad (36)$$

$$\frac{\partial^2 \pi_{L,2}}{\partial n_s \partial q_{L,2}} = -\frac{\partial r}{\partial n_s} - \frac{\partial^2 r}{\partial n_s \partial q_{L,2}} \cdot (q_{L,2}^M - \bar{q}_{L,2}). \quad (37)$$

where

$$\frac{\partial r}{\partial n_s} = c_s'' \frac{q_s^M}{n_s X^2} = \frac{\partial r}{\partial q_L} \cdot q_s^M > 0, \quad \frac{\partial^2 r}{\partial q_{L,j} \partial n_s} = \frac{\partial^2 r}{\partial q_L \partial n_s} - \frac{1}{n_s^2 X^2} \cdot \left(c_s'' + c_s''' \frac{q_s^M}{X} \right). \quad (38)$$

Totally differentiating (27), the effect of a change in n_s on the output of both low-cost vessels is given by

$$\begin{pmatrix} \frac{\partial^2 \pi_{L,1}}{\partial q_{L,1}^2} & \frac{\partial^2 \pi_{L,1}}{\partial q_{L,2} \partial q_{L,1}} \\ \frac{\partial^2 \pi_{L,2}}{\partial q_{L,1} \partial q_{L,2}} & \frac{\partial^2 \pi_{L,2}}{\partial q_{L,2}^2} \end{pmatrix} \begin{pmatrix} dq_{L,1} \\ dn_s \\ dq_{L,2} \\ dn_s \end{pmatrix} = \begin{pmatrix} -\frac{\partial^2 \pi_{L,1}}{\partial n_s \partial q_{L,1}} \\ \frac{\partial^2 \pi_{L,2}}{\partial n_s \partial q_{L,2}} \end{pmatrix}.$$

From (32) through (38), and $(q_{L,1}^M - \bar{q}_{L,1})/n_s + (q_{L,2}^M - \bar{q}_{L,2})/n_s < \bar{q}_s$, the effect of a change in n_s on the sum of the outputs of both low-cost vessels is obtained:

$$\begin{aligned} & \frac{d(q_{L,1} + q_{L,2})}{dn_s} \\ &= \frac{-\left(\frac{c_{L,1}''}{X^2} + \frac{\partial r}{\partial q_L}\right) \cdot \left(2 \frac{\partial r}{\partial n_s} + \frac{\partial^2 r}{\partial q_L \partial n_s} \cdot \{(q_{L,1}^M - \bar{q}_{L,1}) + (q_{L,2}^M - \bar{q}_{L,2})\} + \frac{\partial r}{\partial q_L} \cdot \bar{q}_s\right) - \frac{\partial r}{\partial q_L} \cdot \bar{q}_s \cdot \left(\frac{c_{L,2}''}{X^2} + \frac{\partial r}{\partial q_L}\right)}{\left(\frac{c_{L,1}''}{X^2} + \frac{\partial r}{\partial q_L}\right) \cdot \left(\frac{c_{L,2}''}{X^2} + \frac{\partial r}{\partial q_L}\right) + \left(\frac{c_{L,1}''}{X^2} + \frac{\partial r}{\partial q_L}\right) \cdot \left(\frac{\partial r}{\partial q_L} + (q_{L,2}^M - \bar{q}_{L,2}) \cdot \frac{\partial^2 r}{\partial q_L^2}\right) + \left(\frac{c_{L,2}''}{X^2} + \frac{\partial r}{\partial q_L}\right) \cdot \left(\frac{\partial r}{\partial q_L} + (q_{L,1}^M - \bar{q}_{L,1}) \cdot \frac{\partial^2 r}{\partial q_L^2}\right)} \\ & & - \left(\frac{c_{L,1}''}{X^2} + \frac{\partial r}{\partial q_L}\right) \cdot \left(2 \frac{\partial r}{\partial n_s} + \frac{\partial^2 r}{\partial q_L^2} \cdot q_s^M \cdot \{(q_{L,1}^M - \bar{q}_{L,1}) + (q_{L,2}^M - \bar{q}_{L,2})\}\right) - \frac{\partial r}{\partial q_L} \cdot \bar{q}_s \cdot \left(\frac{c_{L,2}''}{X^2} + \frac{\partial r}{\partial q_L}\right) \\ & < \frac{\left(\frac{c_{L,1}''}{X^2} + \frac{\partial r}{\partial q_L}\right) \cdot \left(\frac{c_{L,2}''}{X^2} + \frac{\partial r}{\partial q_L}\right) + \left(\frac{c_{L,1}''}{X^2} + \frac{\partial r}{\partial q_L}\right) \cdot \left(\frac{\partial r}{\partial q_L} + (q_{L,2}^M - \bar{q}_{L,2}) \cdot \frac{\partial^2 r}{\partial q_L^2}\right) + \left(\frac{c_{L,2}''}{X^2} + \frac{\partial r}{\partial q_L}\right) \cdot \left(\frac{\partial r}{\partial q_L} + (q_{L,1}^M - \bar{q}_{L,1}) \cdot \frac{\partial^2 r}{\partial q_L^2}\right)}{< 0} \end{aligned}$$

From (38), it is clear that $dr/dn_s < 0$ could hold. For example, if the difference between

$c''_{L,1}$ and $c''_{L,2}$ is very small, and c''_S is much greater than $c''_{L,1}$, dr/dn_S is likely to be negative.

The intuition is as follows. The exit of one high-cost fisher decreases the supply of quotas in the second stage. The amount of decrease is equal to $\bar{q}_S - q_S$, which is the same as Subsection 4.3. On the other hand, contrary to the case in which low-cost fishers are price takers, the decrease in demand for quotas is not equal to \bar{q}_S . The reason is that, in the case in which low-cost fishers have market power in the quota market, each low-cost fisher determines how many quotas s/he buys by taking into consideration a change in the quota price. Therefore, it is likely that, the more initial allocation a low-cost fisher holds, the more fish s/he catches. Moreover, this change in the amount of catch affects the behavior of other low-cost fishers. Thus, the amount of decrease in demand for may be smaller than the decrease in supply of quotas in the second stage. In such a case, the quota price increases due to a decrease in the number of high-cost fisher.

Proposition 6: *Suppose that the number of low-cost fishers is constant, and that low-cost fishers have market power in the quota market (in the second stage). Then, the number of high-cost vessels may be greater when each low-cost fisher can determine how many “high-cost fishers” s/he buys than when the total profit is maximized, given the structure of the quota market.*

When $dr/dn_S < 0$, surviving high-cost fishers gains from an exit of a high-cost fisher since the quota price increases. Low-cost fishers, however, do not take into consideration the increase in profits of high-cost fishers. In this case, too many high-cost (inefficient) fishers survive the adjustment process of vessels. In terms of the social optimum, it may be difficult that those high-cost fishers are driven out, and that the efficient harvesting structure is

realized.

5.4 New Entry of Low-cost Fishers

Let us now turn to the third process: entry of low-cost fishers when the number of high-cost fishers is given. Contrary to Subsection 4.4, from (27), it is clear that each low-cost fisher take into consideration the effect of a change in its own amount of catch on the quota price. Therefore, a change in the profit of an incumbent low-cost fisher when a new low-cost fisher enters is given by

$$\frac{d\pi_{L,j}}{dn_L} = -(q_{L,j}^M - \bar{q}_{L,j}) \cdot \left(\sum \frac{\partial r}{\partial Q_L} \cdot \left(\frac{dQ_L^M}{dn_L} - \frac{dq_{L,j}}{dn_L} \right) \right). \quad (39)$$

On the other hand, a change in the profit of an incumbent high-cost fisher is given by

$$\frac{d\pi_{S,k}}{dn_L} = -(q_{S,k}^M - \bar{q}_{S,k}) \cdot \left(\sum \frac{\partial r}{\partial Q_L} \cdot \frac{dQ_L^M}{dn_L} \right). \quad (40)$$

When low-cost fishers have market power in the quota market, initial allocation influences the amount of catch. Thus, the catch by incumbents with positive initial allocation (\bar{q}_L) is different from that by entrants with zero initial allocation. Thus, it is not very easy to obtain the effect of a change in the number of low-cost fishers on the amounts of catch by low-cost fishers formally. However, from (25) and (27), it holds in equilibrium that

$$p(\bar{Q}) - \frac{c'_L}{X} - r - \frac{\partial r}{\partial q_L} \cdot \frac{q_L^M - \bar{q}_L}{n_L} = 0, \quad r = p(\bar{Q}) - c'_S \left(\frac{\bar{Q} - n_L q_L^M}{n_S X} \right) \cdot \frac{1}{X}.$$

Therefore, if all low-cost fishers including entrants have the same amount of initial allocation, it is obtained that $dq_L^M/dn_L < 0$ and $dQ_L^M/dn_L > 0$. Suppose that these inequalities hold when some low-cost fishers have zero initial allocation. Then, when $\tilde{\pi}_L = 0$, it holds from (39) and (40) that

$$\frac{d\Pi}{dn_L} = \tilde{\pi}_L + n_L \frac{d\pi_L}{dn_L} + n_S \frac{d\pi_S}{dn_L} < 0$$

This implies that excess entry of low-cost fishers takes place in terms of social welfare.

6. Improvement of Fishery Management by TAC-ITQ systems in the Presence of Market Power of Low-cost Fishers

We have so far examined the possibility that, given level of TAC, the total profit (resp. the total harvesting cost) is not maximized (resp. minimized). In particular, when low-cost fishers have market power in the quota market, excess entry of low-cost fishers or/and insufficient exit of high-cost fishers may take place. The first best policy is to remove the market power which is the fundamental cause of inefficiency. It, however, may be difficult to force low-cost fishers to behave as price takers. In such a case, kinds of “second best policies” may improve the efficiency. In this section, we consider two possible measures that complement a TAC-ITQ system.

6.1 Vessel Control

The first one is a direct measure: vessel control. When the number of high-cost fishers is too large in terms of efficiency, the government is able to induce them to exit by buying their vessels, the price of which is greater than their profits. This measure is usually called “buy-back program.” This program, however, is often criticized since it also gives inefficient fishers an incentive to invest in their vessels. The larger is a fisher’s vessel, the more payment s/he receives from the government. Therefore, fishers are likely to buy larger vessels than they would buy without a buy-back program. If, however, this program is enforced with regulations on vessel size, it may work for the efficiency of an ITQ program.

Moreover, when it is predicted that the number of transactions of vessels between low-cost and high-cost fishers is too large, or when it is predicted that the number of new

entry of low-cost fishers is too large, regulations on entry may be effective.

The important point is that vessel controls may contribute to improving the efficiency of a TAC-ITQ system, if they are enforced in a way in which additional incentives which work against the efficient resource management are avoided.

6.2 Stock Control

So far, we have not considered the relationship between the fish population biomass and the TAC. The sustainable TAC level is, however, closely related to the reproduction of the biomass.

In general, a simple growth function is defined as shown in Figure 3. The horizontal (resp. vertical) axis measures the biomass stock (resp. the reproduction amount). \hat{X} indicates the biomass stock that yields the Maximum Sustainable Yield (MSY). For simplicity, we assume in this subsection that, when the government sets the target level of the fish population biomass, it keeps setting the TAC equal to the reproduction amount at the target level. Thus, the TAC level, \bar{Q} , is a function of the biomass stock:

$$\bar{Q} = \bar{Q}(X), \quad \bar{Q}'|_{X=\hat{X}} > 0, \quad \bar{Q}'' < 0.$$

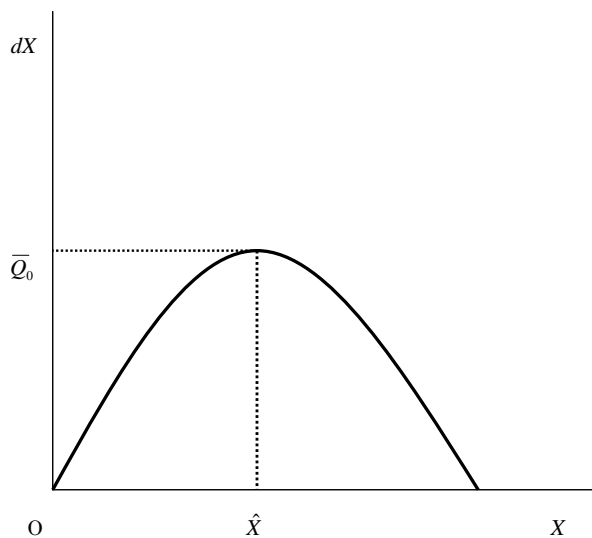


Fig. 3 The Growth function of the fish population biomass

First, we examine the social optimal stock level. In Section 3, we obtained that, at the social optimum, there is no high-cost fishers, and each low-cost fisher catches \hat{q}_L . Moreover, since the marginal cost is equal to the average cost at the optimum, it holds that

$$c'_L\left(\frac{\hat{q}_L}{X}\right) \cdot \frac{1}{X} = \left(c_L\left(\frac{\hat{q}_L}{X}\right) + F_L\right) \cdot \frac{1}{\hat{q}_L}. \quad (41)$$

Total differentiation of (39) yields

$$\frac{d\hat{q}_L}{dX} = \frac{\hat{q}_L}{X} \quad (42)$$

Thus, using (42), it is obtained that, if the condition (41) is satisfied, the effect of a change in the biomass stock on the total cost of each low-cost fisher is given by

$$\frac{d\hat{C}_L}{dX} = \frac{c'_L}{X} \cdot \left(\frac{d\hat{q}_L}{dX} - \frac{\hat{q}_L}{X}\right) = 0. \quad (43)$$

The condition (43) implies that, as far as the minimization of the total harvesting cost of all existing fishers is achieved given biomass stock, a small change in the stock level does not change the total cost of each existing low-cost fisher. On the other hand, the amount of catch and the number of fishers change due to a change in the biomass stock. The optimal number of low-cost fishers in terms of the total harvesting cost minimization is given by $n_L^* = \bar{Q}(X)/\hat{q}_L(X)$. Therefore, it is obtained that

$$\frac{dn_L^*}{dX} = \frac{1}{\hat{q}_L} \cdot \frac{d\bar{Q}}{dX} - \frac{\bar{Q}}{\hat{q}_L^2} \cdot \frac{d\hat{q}_L}{dX} \quad (44)$$

From (42), it is clear that (44) is negative if $X \geq \hat{X}$.

The social welfare is defined as

$$SW = \int_0^{\bar{Q}} p(z)dz - n_L^* \cdot \hat{C}_L.$$

Using (43), the effect of a change in the biomass stock on the social welfare is given by

$$\begin{aligned}
\frac{dSW}{dX} &= p(\bar{Q}) \cdot \frac{d\bar{Q}}{dX} - \hat{C}_L \cdot \frac{dn_L^*}{dX} \\
&= p(\bar{Q}) \cdot \frac{d\bar{Q}}{dX} - AC' \cdot \hat{q}_L \cdot \frac{dn_L^*}{dX} \\
&= p(\bar{Q}) \cdot \frac{d\bar{Q}}{dX} - AC' \cdot \frac{d\bar{Q}}{dX} + AC' \cdot n_L^* \cdot \frac{d\hat{q}_L}{dX},
\end{aligned} \tag{45}$$

where AC' denotes the average cost, $AC_L(\hat{q}_L)$. Since $d\bar{Q}/dX = 0$ at \hat{X} , from (42), the following proposition holds.

Proposition 7: *A small increase in the target biomass level from \hat{X} , which yields the MSY, increases the social welfare.*

Let us now turn to the market equilibrium. For simplicity, in the following, we theoretically examine the effect of a change in the biomass stock on the social welfare given number of both types of fishers. Then, we discuss entry and exit descriptively. From the definition of the total cost, (2), it is obtained that:

$$\frac{dTC}{dX} = -c'_L \frac{Q_L^h}{X^2} + c'_L \frac{1}{X} \frac{dQ_L^h}{dX} - c'_S \cdot \frac{Q_S^h}{X^2} + c'_S \frac{1}{X} \frac{dQ_S^h}{dX}, \quad h = T, M, \tag{46}$$

where $Q_i^h = \sum q_i^h$ ($i = L, S$). Since high-cost fishers are price takers, $r + c'_S/X = p$ holds.

Hence, from (46), and the fact that $\bar{Q} = Q_L^h + Q_S^h$ ($h = T, M$), the effect of a change in the target level of the biomass stock on the social welfare is given by

$$\begin{aligned}
\frac{dSW}{dX} &= r \cdot \frac{d\bar{Q}}{dX} + c'_L \frac{Q_L^h}{X^2} - c'_L \frac{1}{X} \frac{dQ_L^h}{dX} + c'_S \cdot \frac{Q_S^h}{X^2} + c'_S \frac{1}{X} \frac{dQ_L^h}{dX} \\
&= r \cdot \frac{d\bar{Q}}{dX} + c'_L \frac{Q_L^h}{X^2} + c'_S \cdot \frac{Q_S^h}{X^2} + \frac{1}{X} \frac{dQ_L^h}{dX} \cdot (c'_S - c'_L), \quad h = T, M
\end{aligned} \tag{47}$$

When both types of fishers are price takers, $c'_S = c'_L$ holds. Therefore, the following proposition is obtained.

Proposition 8: *Suppose that both types of fishers are price takers in the quota market. A small increase in the target biomass level from \hat{X} , which yields the MSY, increases the social welfare for any given numbers of both types of fishers.*

There are two kinds of factors. First, an increase in the biomass lowers the variable costs of both types of fishers for catching a certain amount of fish. This effect is represented by the second and third terms in the second line of (47). This effect works for the reduction of the total harvesting cost. Second, the shift of harvesting from one type of fishers to the other takes place, which is represented by the first and fourth terms in the second line of (47). Whether this effect works for or against the cost reduction is generally ambiguous. In the case in which both types of fishers are price takers, the second factor does not exist. Thus, the social welfare increases.

When low-cost fishers have market power in the quota market, $c'_s > c'_L$ holds. Therefore, whether or not a small increase in the biomass stock from \hat{X} increases the social welfare depends on the sign and the scale of dQ_L^h/dX . If $dQ_L^h/dX > 0$, which means that the amount of catch shifts from high-cost to low-cost fishers, a small increase in the biomass stock from \hat{X} increases the social welfare. On the other hand, if $dQ_L^h/dX < 0$, the social welfare may reduce. This result is intuitive. The marginal cost of high-cost fishers is higher than that of low-cost fishers. Therefore, the shift from fishing with a low marginal cost to fishing with a high marginal cost may increase the total harvesting cost.

The important point is as follows. In terms of the social optimum, the target biomass stock should be higher than \hat{X} . In the case in which both types of fishers are price takers, the setting of the biomass stock higher than \hat{X} is likely to improve the social welfare, since the optimal number of low-cost fishers is likely to be achieved through the three kinds of processes examined in Section 4 for any given level of TAC.

On the other hand, in the case in which low-cost fishers have market power in the quota market, a small increase in the biomass stock from \hat{X} may reduce the efficiency of harvesting to catch a certain amount of fish. Moreover, if $dQ_L^h/dX < 0$, it becomes more difficult to induce high-cost fishers to exit from the fishery. Therefore, the setting of the biomass stock level higher than \hat{X} may not work for the efficiency under an ITQ program.

7. Concluding Remarks

In this paper, first, we have theoretically examined whether a TAC-ITQ system is able to achieve efficiency. “Efficiency” implies the minimization of the total harvesting cost (the sum of the total cost of all existing fishers) for and/or the maximization of the sum of all fishers’ profits from catching a certain amount of fish. In particular, we consider two cases on the structure of the quota market: the case in which all fishers are price takers, and the case in which some fishers with low-cost vessels have market power in the quota market.

We demonstrated that, when all fishers are price takers in the quota market, the social optimum is likely to be achieved given TAC level. One factor of inefficiency is that the number of transactions between low-cost and high-cost fishers is too large, and that the number of high-cost fishers is too small, when the number of low-cost fisher is fixed. On the other hand, when low-cost fishers have market power in the quota market, the inefficiency may be more serious: excess entry of low-cost fishers and insufficient exit of high-cost fishers may take place.

Second, we have discussed the possibility of complementary measures which are able to improve the efficiency of an ITQ program. Vessel controls and stock targeting are investigated, and it is demonstrated that those measures may work for a TAC-ITQ system.

In this paper, we divided the determination of vessel numbers into three processes, and

examined each process separately. In reality, all processes proceed at the same time. It is our future task to find equilibria for various types of market structures by taking into consideration those three transaction processes.

References

- [1] Adelaja, Adesoji, B. Mccay, and J. Menzo (1998). Market structure, capacity utilization, resource conservation, and tradable quotas, *Marine Resource Economics* 13, 115-134.
- [2] Anderson, Lee G. (1991). A note on market power in ITQ fisheries, *Journal of Environmental Economics and Management* 21, 291-296.
- [3] Arnason, Ragnar (1993). The Icelandic individual transferable quota system: a descriptive account, *Marine Resource Economics* 8, 201-218.
- [4] Bergland, Harald, and Pedersen, P. A. (2006). Risk attitudes and individual transferable quotas, *Marine Resource Economics* 21, 81-100.
- [5] Boyce, John R. (2004). Instrument choice in a fishery, *Journal of Environmental Economics and Management* 47, 183-206.
- [6] Clark, Colin, W. (2006). *The Worldwide Crisis in Fisheries -- Economic Models and Human Behavior* --. Cambridge University Press.
- [7] Clark, Ian, N., Philip J. Major, and N. Mollett (1988). Development and implementation of New Zealand's ITQ management system, *Marine Resource Economics* 5, 325-349.
- [8] Danielsson, Asgeir (2000). Efficiency of ITQs in the presence of production externalities, *Marine Resource Economics* 15, 37-43.
- [9] Gauvin, John R., Ward, J. M., and Burgess, E. E. (1994). Description and evaluation of the wreckfish (*polyprion americanus*) fishery under individual transferable quotas, *Marine Resource Economics*, 9, 99-118.

[10] Matulich, Scott C., and M. Sever (1999). Reconsidering the initial allocation of ITQs: the search for a Pareto-safe allocation between fishing and processing sectors, *Land Economics* 75, 203-219.

[11] Squires, Dale, and J. Kirkley (1996). Individual transferable quotas in a multiproduct common property industry, *Canadian Journal of Economics* 29, 318-342

[12] Weninger, Quinn. (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.

[13] Vestergaard, Niels, F. Jensen, and H. P. Jorgensen (2005). Sunk cost and entry-exit decisions under individual transferable quotas: why industry restructuring is delayed, *Land Economics* 81, 363-378.