# DISCUSSION PAPER SERIES

**Discussion paper No.68**

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January 2011

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# On Efficiency of Individual Transferable Quotas (ITQs) through Reduction of Vessels

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This version: January 2011

**Abstract**

This paper theoretically examines whether an individual transferable quotas (ITQs) regime can achieve the long-run efficiency through the reduction of vessel numbers. Assuming the existence of two types of vessels in terms of their scales, we consider not only quota transactions but also the exit of fishers. Changes in vessel sizes of incumbent fishers are also taken into consideration. We find that when large-scale vessels are more efficient than small-scale vessels, the long-run efficiency is achieved only with an ITQ regime. However, when small-scale vessels are more efficient than large-scale vessels, the long-run efficiency is not achieved; the number of vessels becomes too few compared to when the total harvesting cost is minimized.

**Key Words**: Efficient fishery, fishery management, individual transferable quotas, quota transaction, vessel scale.

**JEL Classification**: Q22, Q28.

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[‡] Authors are grateful to Tetsuya Nakajima, Akira Maeda, Hideki Nakamura, Masayuki Komatsu, Hisashi Kurokura, Nobuyuki Yagi, and Toshio Katsukawa for helpful comments. We also gratefully acknowledge the financial supports from Research Institute of Economy, Trade & Industry, and the Japan Society for the Promotion of Science under a Grant-in-Aid for Scientific Research (B).

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## 1. Introduction

Having faced the depletion of fish stocks all over the world, governments have adopted many types of resource management measures over the past several decades, including technical measures and input and output controls. Among those measures, the individual transferable quotas (ITQs) regime is considered to be the most effective. Under this regime, a government sets the total allowable catch (TAC) and determines the initial allocation of quotas to fishers. Then, it establishes the market for quota transactions. Similar to regimes of tradable allowances in other fields of environmental and resource issues, such as tradable emission permits, a TAC-ITQ regime (referred hereafter as the ITQ regime) is able to achieve two goals at the same time: it can control the total amount of catch and, accordingly, the resource stock while achieving economic efficiency. Less efficient fishers sell their quota holdings to more efficient fishers instead of using the quotas for themselves. Thus, excess competition and over capacity are avoided, and the total cost of catching a certain amount of fish is minimized.[1]

Strictly speaking, there are two types of efficiency: the short-run and the long-run efficiency. With the former, the total cost is minimized in each period (fishing season) given the fixed number and the sizes of vessels. For the latter, the total cost is minimized by adjusting the number and the sizes of vessels, assuming that the short-run efficiency is achieved. Theoretically, if the quota market is competitive and if free entry/exit is assured, both the short-run and long-run efficiencies can be achieved under an ITQ regime.[2]

In reality, however, the two premises may not be satisfied in many cases. When the participants of regimes are few or when there are dominant players, these may have the

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[1] There are more effects in terms of efficiency. For example, fishers can determine when they catch fish to maximize their own profits, because they do not need to be catching fish at a stretch. Thus, when fish prices are low (resp. high), fishers have weak (resp. strong) incentives to catch fish. As a result, fish prices become stable. For the basic analysis of ITQ regimes, see Clark (2006) for example.

[2] For example, see Spulber (1985) for the theoretical analysis of tradable effluent permits.

market power when selling and buying quotas. In this case, the short-run efficiency is not achieved.[3]

On the other hand, it is usually costly to enter the fishery because new entrants have to pay a large amount of fixed costs, including the cost for acquiring the techniques specific to fishing activities.[4] Sometimes fishery cooperatives restrict new entrants, and it is time-consuming for entrants to settle into fishers' communities even without clear substantive restrictions. Moreover, the authorities may also consider the restriction of new entrants because there are usually too many vessels compared to the number needed for efficiency before the introduction of an ITQ regime.[5] Alternatively, the authorities may face political pressure from established fishers for entry restriction. In these cases, the long-run efficiency may be either not achieved or delayed.[6]

This paper focuses on the long-run efficiency in the presence of entry barriers and examines when the efficiency is (and is not) achieved with only an ITQ regime through reduction of vessels. In particular, our analysis focuses on the following three types of real situations.

First, we consider the situation in which there are too many vessels/fishers before the introduction of an ITQ regime in terms of efficiency. According to the literature evaluating the ITQ regimes that have been adopted in New Zealand, Iceland, and other countries, excess entry was verified in all of the fisheries in those countries.[7]

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3 See Anderson (1991) and Armstrong (2008) for the theoretical analysis under imperfect competition.

4 Rosendahl and Storrøsten (2010) assumed that new entrants have to pay an additional fixed cost in their theoretical analysis.

5 Newell et al. (2005) referred to measures that may accompany ITQ regimes. According to the FAO (2006, 2008), there are usually license schemes in many countries, regardless of whether or not ITQ regimes have already been introduced. For example, there are strict regulations on new entry in many coastal and offshore fishing areas in Japan both formally and informally. Although Japan has not yet introduced any ITQ regimes, it has already introduced TAC regimes, and it is now considering the introduction of ITQs. However, it cannot be assumed that all of those entry regulations will be removed when the ITQs are implemented.

6 See Weninger and Just (2002) and Vestergaard et al. (2005) for example.

7 For the evaluation of ITQ regimes, see Clark et al. (1988), Arnason (1993), Gauvin et al. (1994),

Second, assuming the existence of a heterogeneous cost structure for vessels, we considered two cases: one in which large-scale vessels are more efficient than small-scale ones and one in which small-scale vessels are more efficient than large-scale ones. When there are a lot of traditional small-scale fishers before the introduction of an ITQ regime and there are no effective measures of resource management, fishers do not have incentives to introduce large-scale vessels with a large amount of fixed cost because the amount of catch will be much less than the minimum efficiency level. Thus, it is likely that the former case holds.

However, when only TAC is introduced, it is generally thought that an excess of investment occurs and that the scales of vessels become too large in terms of efficiency. This is because fishers have to compete for fish with better technology, larger vessels, and higher speed. In such a case, it is likely that the latter case holds. Lian et al. (2010) and Weninger (2008) empirically concluded that medium-size vessels are more efficient than small- and large-sized vessels in the case of the Pacific Coast groundfish fishery and the Gulf of Mexico Grouper Fishery.[8] Our analysis can be certainly applied to cases in which there are more than two types of vessels.

Third, we consider both the vessel and quota transactions. Under ideal ITQ regimes, a fisher is able to sell all of quota holdings to another fisher and exit from the fishery, which we call "*vessel transaction*" in our analysis. Fishers also adjust their quota holdings by selling/buying relatively small amount of quotas in the quota market. Thus, these two types of transactions should be taken into consideration to investigate the long-run efficiency of ITQ regimes. Moreover, in reality, after an ITQ regime is introduced, the vessel scales owned by existing fishers change over time. Therefore, we also took into consideration the

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Weninger (1998), and Dupont and Grafton (2001) among others. Moreover, Matthiasson (1996) theoretically analyzed the situation in which the vessel number becomes too large by introducing the cost of implementing measures.

[8] Brandt (2007) also conducted empirical studies and obtained the mean efficiency according to vessel sizes.

changes in vessel scales that are chosen by the fishers. Weninger and Just (2002) and Vestergaard et al. (2005) considered the non-malleability of capital, and they theoretically demonstrated the delay of exit. Rosendahl and Storrøsten (2010) examined the effects of allocation schemes on entry/exit. However, they did not deal with the two types of vessel transactions and scale changes explicitly.

In contrast to the literature analyzing the tradable emission permits, we simplify the following two factors in the analysis. First, fishing quotas are allowances for the output. To focus on the quota transactions and the fluctuation of quota prices, we consider the TAC as constant. Accordingly, because the output is regulated by the TAC, we consider the fish/output price as constant.[9] Second, we exclude the "banking" of quotas because it is usually not permitted in terms of resource management.

We find that when large-scale vessels are more efficient than small-scale vessels, the long-run efficiency is achieved only with an ITQ regime. However, when small-scale vessels are more efficient than large-scale vessels, the long-run efficiency is not achieved; the number of vessels becomes too few compared to when the total cost is minimized.

The structure of the paper is as follows. Sections 2 and 3 describe the basic model and the social optimum, respectively. Section 4 investigates the long-run efficiency after describing the quota transactions. Section 5 refers to the extension, and Section 6 provides the concluding remarks.

## 2. The Basic Model

Consider a fishery in which there are $n_L$ fishers who have been engaging in fishing with large-scale vessels and $n_S$ fishers who have been engaging in fishing with small-scale

[9] We do not delve into uncertainty, because our focus is on vessel scales/exit and the long-run efficiency. Uncertainty, however, can affect the efficiency of fishing under ITQ regimes. See Bergland and Pederson (2006), for example. Moreover, in reality, the TAC may vary according to the resource stock changes.

vessels in the initial period. Each fisher uses one vessel and harvests fish stock of single species. All large-scale vessels are identical, and all small-scale 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 type of vessels. We exclude the possibility of new entry because of entry costs or/and regulations.

The cost structure of each type of vessel is:

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

where $q_i$, $c_i$, and $F_i$ denote the amount of catch, the variable cost, and the fixed cost of a fisher of type $i$ $(i = L, S)$, respectively.[10] It is assumed that $F_L > F_S$, and $c_L' < c_S'$ for any given amount of catch. Moreover, because 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, $\hat{q}_i$ $(i = L, S)$, and $\hat{q}_L > \hat{q}_S$ holds.

We define the two cases as follows.

**Definition 1:** *When* $AC_L(\hat{q}_L) < AC_S(\hat{q}_S)$ *holds, it is Case A, whereas when* $AC_L(\hat{q}_L) > AC_S(\hat{q}_S)$ *holds, it is Case B.*

Both cases are depicted in Figures 1 (a) and (b). In what follows, let subscripts A and B denote Case A and Case B, respectively, when we need to discriminate between the two cases. Theoretically, Case A is likely to arise when the fixed cost of a large-scale vessel is not very large, and the marginal cost of a small-scale vessel is relatively high. However, Case B is likely to arise when the fixed cost of a large-scale vessel is relatively large, and the marginal cost of a small-scale vessel is not very high.

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[10] In the literature of the analyses of fishery economics, fish biomass stock is included in the cost function. Moreover, the stock is combined with the variable that represents the fishing effort, when the effort is explicitly described. In this paper, those variables do not materially affect the main results. Therefore, we drop those variables. See, for example, Clark (2006), and Danielsson (2000) for cost structures.

As noted in the introduction, when there are no effective measures for fishery management or when there are only vessel-quotas, either case can exist before an ITQ regime is introduced.[11] For example, consider the situation in which there are many traditional small-scale fishers, vessels quotas are allocated, and there is no quotas transaction scheme. In this case, it is likely that a large-scale vessel cannot get a large amount of quotas and, accordingly, it cannot catch a large amount of fish to make profits, as a fisher usually has to pay a large fixed cost to operate a large-scale vessel. Thus, without an ITQ regime, small-scale fishers do not have incentives to shift their vessels to large-scale ones, and a situation like Case A can exist. However, if there are no effective measures for resource management, there is excessive competition between fishers. In such a case, an excess of investments can easily occur on vessel sizes, fishing gears, and so on. Thus, a situation like Case B can exist. Even when TAC is implemented without any quota transaction scheme, the situation like Case B can arise.

The government introduces an ITQ regime for the fishery: it sets the TAC, which is denoted by $\overline{Q}$, determines the initial allocation to each fisher, and establishes the quota market. In the present context, the "ITQ" includes both vessel transactions and quota transactions explained below. The amount of $\overline{Q}$ is fixed in this model. The initial allocation is also exogenous for fishers, although the quota holdings of fishers can change through vessel transactions.[12]

Then, the total harvesting cost for the society ($TC$) is:

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[11] Moreover, it is also possible that three types of vessels exist in reality: the middle-scale vessel is the most efficient, and the small-scale and large-scale vessels are less efficient than the middle-scale one. Our analysis can be applied to this situation.

[12] Our results are not influenced by the initial allocation, although the initial allocation can determine whether a situation like Case A or Case B holds. In reality, it is natural to consider that $\overline{q}_L > \overline{q}_S$, because the initial allocation is usually determined according to the past fishing activities (the past catching amounts). Theoretically, however, the results do not change whether or not this assumption is made.

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

where $\sum q_{L,j} + \sum q_{S,k} = \overline{Q}$.

The demand curve for fish is downward sloping:

$$p = P(\overline{Q}), \qquad P' < 0,$$

where $p$ denotes the fish (output) price. Because the TAC level is fixed, the price of fish does not change. It should be noted that this fish price is different from the quota price. As explained in Section 4, the quota price changes because vessel numbers change and because quotas are traded in the quota market.

We consider the following processes in determining the harvesting structure. In each period, in the first stage, a pair of fishers is "*randomly*" chosen.[13] Each fisher of the pair is given a chance to make a deal of purchasing all of the quotas owned by the other fisher, selling all of her/his own quotas to the other fisher, or shifting her/his vessel to the other type. Hereafter, we call each of the first two cases "*vessel transaction*" and the last case "*vessel shift*". In the case of vessel transactions, both fishers have to agree on the terms of the contract, and the seller exits from the fishery. Each fisher is also allowed to do nothing. Observing the situations in the real world, we set up the following assumptions on these vessel transactions/shifts for the clarity of the theoretical analysis.

**Assumption 1:** *When more than two fishers assemble and negotiate for a contract from which every participant gains, it is very costly and time consuming. Therefore, a contract of a vessel transaction is always made between two fishers.*

13 The number of pairs chosen in each period does not matter. The possibility that the efficient harvesting structure is achieved is the strongest under the setting of "one pair in each period". Our purpose is to demonstrate the possibility that inefficient situations can be generated with an ITQ regime. Thus, with more than one pair in each period, our results become more robust. This point is referred to in Subsection 4.3.

**Assumption 2:** *Fishers do not have an incentive to do a vessel transaction/shift unless their profit increases by the transaction/shift. In other words, if their profit increases by the transaction/shift, they always make a contract of a vessel transaction or shift their vessel scales.*

Thus, the fishers of a pair, who are randomly chosen, do not search for other fishers to establish contracts.[14] Moreover, if the profits before and after a vessel transaction/shift are equal to each other, a fisher does not have an incentive to perform a vessel transaction/shift.[15]

We assume that there are too many fishers in terms of the long-run efficiency in the initial period, and we exclude new entry of fishers. As noted in the introduction, there are many examples of entry restrictions in the real world, and it is also very costly for new entrants to pay a large amount of fixed cost, including the cost for acquiring the techniques specific to fishing activities. In general, the authorities aim to decrease the vessel numbers to improve the efficiency of fishing activities. Given these factors, we focus on the possibility of achieving efficiency through the reduction of vessel numbers.

Once the two fishers decide on what to do about vessel transactions/shifts, the second stage begins. Each fisher who keeps engaging in fishing activities pays a fixed cost for her/his own vessel.[16] Then, the quotas are transacted between fishers. Hereafter, we call this type of transaction as "*quota transactions*". In this stage, each fisher does not sell all the

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[14] Because two fishers are chosen randomly, Assumption 1 does not harm the generality of our analysis. Although we assume that a contract of a vessel transaction is always made between two fishers for clarity, the important point is that it is very costly and impossible for all fishers in the fishery to gather at the same time and find the optimal solution.

[15] Assumption 2 can be justified if we consider the existence of a small switching/exit cost.

[16] This is a kind of rental price of capital. The fixed cost of a large-scale vessel for a fisher who has been a small-scale fisher for a long time may be larger than that for a fisher who has already been a large-scale fisher, because there may be switching costs and any previous experience may lower the fixed cost. For simplicity, however, they are assumed to be the same. The existence of the switching costs does not materially change the results. We will refer to this point in Section 5.

quotas s/he holds, which implies that no fisher exits. Quotas are transacted in a perfectly competitive market.

Because we do not need to explicitly describe the period, we omit the notation for the periods in the following analysis. Moreover, for theoretical consistency, we made the following assumption.

**Assumption 3:** *Fishers are "complete" price takers.*

**Assumption 4:** *Fishers decide on vessel transactions/shifts according to instantaneous benefits, which are the benefits gained in the period in which the transactions/shifts take place given the quota price.*

Assumption 3 means that each fisher takes the quota price as given not only when s/he conducts the quota transactions but also when s/he chooses a vessel transaction/shift. In other words, fishers expect that the quota price in the previous period also holds in the present period when they determine vessel transaction/shifts.[17] Assumption 4 means that fishers do not consider changes in the benefits in the future. Vessel transactions/shifts are sometimes time consuming and, accordingly, it takes a long time for the harvesting structure to be adjusted.[18] Therefore, fishers are assumed not to take into consideration all of transactions/shifts which will be done by other fishers in the future when they determine

[17] Weninger and Just (2002), Vestergaard et al. (2005) and Rosendahl and Storrøsten (2010) examined the entry/exit problem under ITQ regimes. Weninger and Just (2002) and Vestergaard et al. (2005) considered the quota price as exogenous and constant. Although Rosendahl and Storrøsten (2010) allowed the change in the quota price over the periods, they did not relate the quota price to the number of fishers. In reality, however, one vessel transaction/shift may be accompanied by a transaction of a large amount of quotas at one time, or that the total demand for quotas could change drastically. Therefore, fishers may predict the effect of a vessel transaction/shift on the quota price. The basic results do not materially change even if we take into consideration the expectation of fishers on the price effects. We will refer to this point in Section 5.

[18] See Weninger and Just (2002) and Vestergaard et al. (2005) for the theoretical analyses.

their own vessel transactions/shifts. Moreover, this assumption is consistent with the assumption of "complete price takers".

## 3. The Social Optimum

First, we examine the social optimum to catch a certain amount of fish, which is regulated by TAC. Because the fish price is constant, the objective is to minimize the total harvesting cost, (2). The total cost minimization problem, given both types of vessel numbers can be written as:

$$\underset{q_{L,j},q_{S,k}}{Min} \sum_{j=1}^{n_L}\left\{c_L\left(q_{L,j}\right)+F_L\right\}+\sum_{k=1}^{n_S}\left\{c_S\left(q_{S,k}\right)+F_S\right\},$$

$$s.t. \sum q_{L,j}+\sum q_{S,k}=\overline{Q},$$

where $j$ and $k$ are indices of fishers. Then, the following first-order conditions (FOCs) are obtained:

$$c'_{L,j}=c'_{S,l}, \qquad c'_{S,k}=c'_{S.l} \quad (k \neq l). \tag{3}$$

Thus, the equilibrium outputs are written as $q_i^*\left(n_S, n_L, \overline{Q}\right)$ $(i=L,S)$, and the total harvesting cost can be rewritten as follows:

$$TC=n_L\left\{c_L\left(q_L^*\right)+F_L\right\}+n_S\left\{c_S\left(q_S^*\right)+F_S\right\}. \qquad (2)'$$

Thus, the total cost is minimized when both types of vessel numbers are chosen such that (2)' is minimized.

Let us focus on Case A. First, suppose that $\overline{Q}/\hat{q}_{L,A}$ is an integer. Then, it is clear that the average cost is minimized when the number of large-scale (resp. small-scale) vessels is $\overline{Q}/\hat{q}_{L,A}$ (resp. zero), and each large-scale vessel catches $\hat{q}_{L,A}$. In this case, considering that the TAC and the fish price are fixed, the total cost (resp. the social surplus) is also minimized (maximized).[19]

Second, suppose that $\overline{Q}/\hat{q}_{L,A}$ is not an integer, and let us define $\hat{n}_{L,A}$ as an integer such that $\hat{n}_{L,A} < \overline{Q}/\hat{q}_{L,A} < \hat{n}_{L,A} + 1$. Consider the case in which the number of small-scale fishers is zero. Then, the number of large-scale fishers that minimizes the total harvesting cost is either $\hat{n}_{L,A}$ or $\hat{n}_{L,A} + 1$. In either case, the average cost is higher than $AC_{L,A}(\hat{q}_{L,A})$. In the case of $\hat{n}_{L,A}$ (resp. $\hat{n}_{L,A} + 1$), each large-scale vessel catches the amount greater (resp. smaller) than $\hat{q}_{L,A}$. If the average cost is higher than $AC_{S,A}(\hat{q}_{S,A})$, it may be that the total harvesting cost when $\hat{n}_{L,A}$ large-scale vessels and some small-scale vessels are operating is lower than when only large-scale vessels are operating. For example, when the number of large-scale vessels is $\hat{n}_{L,A}$, it is likely that the operation of an additional small-scale vessel decreases the average cost of each large-scale vessel as the amount of catch gets closer to $\hat{q}_{L,A}$.

Case B can be analyzed analogously. For clarity of the following analyses, we made the following assumption.

**Assumption 5:** *In Case A (resp. Case B),* $\overline{Q}/\hat{q}_{L,A}$ *(resp.* $\overline{Q}/\hat{q}_{S,B}$ *) is an integer.*

Then, the following proposition holds.

**Proposition 1:** *At the social optimum, in Case A (resp. Case B), the harvesting structure is such that (a) only large-scale (resp. small-scale) vessels are operating, (b) the number of*

19 It should be noted repeatedly that the fish price is different from the quota price. If we neglect the integer problem, the fact that the total cost is minimized can be easily verified. See Appendix A.

*operating vessels is* $\overline{Q}/\hat{q}_{L,A}$ *(resp.* $\overline{Q}/\hat{q}_{S,B}$ *), and (c) each fisher which engages in fishing catches* $\hat{q}_{L,A}$ *(resp.* $\hat{q}_{S,B}$ *).*

In the following analysis, we assume that there are more than $\overline{Q}/\hat{q}_{L,A}$ (resp. $\overline{Q}/\hat{q}_{S,B}$ ) fishers in Case A (resp. Case B) before the introduction of a TAC-ITQ regime, which means that there are too many fishers in terms of efficiency.

## 4. Transactions of Quotas/Vessels and Long-run Efficiency

In this section, we describe quota transactions and vessel transactions/shifts. Then, we investigate whether an ITQ regime is able to achieve the long run efficiency (the social optimum). To begin with, we describe the equilibrium in the quota market.

### 4.1 Quota Transactions in the Quota Market

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

$$\pi_{L,j} = p(\overline{Q})q_{L,j} - C_L(q_{L,j}) - r \cdot (q_{L,j} - \breve{q}_{L,j}), \tag{4}$$

$$\pi_{S,k} = p(\overline{Q})q_{S,k} - C_S(q_{S,k}) - r \cdot (q_{S,k} - \breve{q}_{S,k}), \tag{5}$$

where $r$ and $\breve{q}_i$ denote the price of quota and the quota holdings in the beginning of the quota transaction stage in each period, respectively.[20] In the following, we omit the indices of fishers, $j$ and $k$, unless they are needed. The FOCs are:

$$p(\overline{Q}) - c'_L - r = 0, \qquad p(\overline{Q}) - c'_S - r = 0\,. \tag{6}$$

[20] This quota holding is different from the initial allocation, because the amount of quota holdings of a fisher changes after a vessel transaction is made in the first stage of past periods. This difference, however, does not matter for the present analysis.

Each large-scale (resp. small-scale) fisher harvests $q_L^T(n_L, n_S, \overline{Q})$ (resp. $q_S^T(n_L, n_S, \overline{Q})$) such that the following conditions are satisfied:

$$c'_L(q_L^T) = c'_S(q_S^T), \tag{7}$$

$$n_L q_L^T + n_S q_S^T = \overline{Q}. \tag{8}$$

It should be noted that because all fishers are price takers, the amounts of catches are not influenced by initial quota holdings ($\breve{q}_{L,j}, \breve{q}_{S,k}$) given the numbers of both types of fishers. From (6), the equilibrium quota price is obtained: $r(n_L, n_S, \overline{Q})$.

Each fisher expects that the quota price does not change by a change in both types of vessel numbers when s/he chooses a vessel transaction/shift. According to (8), however, a change in the number of vessels actually affects the amounts of the catches and the price of the quotas.

A vessel transaction defined in Section 2 means that the number of either type of vessel decreases. In such a case, the total demand for quotas decreases given the quota price. This change in demand leads to a decrease in the quota price, because the supply of quotas is fixed by TAC. Because $c''_i > 0$, from (6), a decrease in the number of either type of vessel increases the amount of catch of each incumbent vessel.[21]

Similarly, because it is assumed that $c'_L < c'_S$ for any given amount of catch, a vessel shift from a small-scale (resp. a large-scale) to a large-scale (resp. a small-scale) increases (resp. decreases) the total demand for quotas given the quota price. This change in demand leads to an increase (resp. a decrease) in the quota price.

### 4.2 Vessel Transactions/Shifts and Equilibria

In this subsection, we examine the equilibria, when both vessel transactions and shifts could

[21] To capture this point intuitively, we provide the continuous case in Appendix B.

take place. There is, however, no new entry. First, we set up the definition of equilibria on the harvesting structure.

**Definition 2:** *At equilibrium, (a) a fisher does not have an incentive to shift her/his vessel size when s/he is randomly chosen, and (b) a contract of vessel transaction cannot be made between any randomly chosen two fishers.*

Let us begin with Case A. First, suppose that $r > p - AC_{L,A}(\hat{q}_{L,A})$. In this case, for both small-scale and large-scale fishers, $MC_{i,A}(q_{i,A}^T) < AC_{i,A}(q_{i,A}^T)\,(i = L, S)$ and $q_{i,A}^T < \hat{q}_{i,A}$ hold. Moreover, from (6), $p - MC_{i,A}(q_{i,A}^T) = r$ holds. Because the profit from catching a unit of fish is $p - AC_{i,A}(q_{i,A}^T)$, $\pi_{i,A} < r\breve{q}_{i,A}$ holds whether a fisher is a seller or a buyer of quotas in the quota market (in the second stage). Figures 2 (a) indicates the case in which a fisher is a seller. The shaded area is the profit of the fisher. On the other hand, Figure 2 (b) indicates the case in which a fisher is a buyer. The shaded area minus the dotted area is the profit of the fisher.

However, each fisher of a pair, who is randomly chosen, has an incentive to offer a price that is greater than the profit of the other fisher in the first stage. This is because s/he is a price taker, and s/he expects that her/his profit will increase by $r\breve{q}_{m,A}$, where the subscript $m$ denotes the other fisher of the pair. Although one of the two fishers, who are randomly chosen, may have an incentive to shift her/his vessel type, the quota holdings ($\breve{q}_{i,A}$) do not change because of vessel shifts. Therefore, the profit of the fisher is less than $r\breve{q}_{i,A}$ even after s/he did a vessel shift. The price offered by the other fisher of a pair must be more attractive for the fisher than the profit s/he can gain after shifting her/his own vessel type.

Thus, a vessel transaction takes place. Moreover, because the number of fishers decreases, the quota price decreases.

**Lemma 1:** *In Case A, there is no equilibrium in which the quota price is greater than* $p - AC_{L,A}(\hat{q}_{L,A})$.

Secondly, suppose that $p - AC_{S,A}(\hat{q}_{S,A}) < r \leq p - AC_{L,A}(\hat{q}_{L,A})$ . In this case, $MC_{S,A}(q^T_{S,A}) < AC_{S,A}(q^T_{S,A})$ and $MC_{L,A}(q^T_{L,A}) > AC_{L,A}(q^T_{L,A})$ holds. Thus, whether fishers are sellers or buyers of quotas in the quota market (the second stage), $\pi_{S,A} < r\breve{q}_{S,A}$ and $\pi_{L,A} \geq r\breve{q}_{L,A}$ hold. The shaded area of Figure 3 indicates the profit of a large-scale fisher who is a buyer of quotas in the quota market. If a small-scale fisher shifts her/his vessel to a large-scale one, s/he expects that her/his profit will be equal to or greater than $r\breve{q}_{S,A}$. Therefore, a small-scale fisher has an incentive to shift her/his vessel to a large-scale one. Nevertheless, no other fisher has an incentive to offer the price that is equal to or greater than $r\breve{q}_{i,A}\ (i = L, S)$ . Thus, when $p - AC_{S,A}(\hat{q}_{S,A}) < r \leq p - AC_{L,A}(\hat{q}_{L,A})$, vessel shifts from small-scale vessels to large-scale ones take place, and the quota price increases.

Thirdly, suppose that $r \leq p - AC_{S,A}(\hat{q}_{S,A})$. Similar to the previous case, no vessel transactions take place. However, from the assumption of Case A, it holds that

$$AC_{L,A}(\hat{q}_{L,A}) < AC_{S,A}(\hat{q}_{S,A}) < AC_{S,A}(q^T_{S,A}) < MC_{S,A}(q^T_{S,A}) = p - r .$$

Thus, whether $\breve{q}_{S,A}$ is larger or smaller than $\hat{q}_{L,A}$, a small-scale fisher expects that her/his profit will increase if s/he shifts her/his vessel to a large-scale one and catches the amount of $\hat{q}_{L,A}$. Moreover, the profit will increase further if s/he chooses the amount of catch so that the marginal cost of catch is equal to the gap between the fish and quota prices. Thus, a small-scale fisher has an incentive to shift her/his vessel to a large-scale one, and the quota price increases by the vessel shift.

**Lemma 2:** *In Case A, there is no equilibrium in which (a)* $r \le p - AC_{L,A}(\hat{q}_{L,A})$ *holds, and (b) there is one or more than one small-scale fisher.*

Because there are too many fishers in terms of efficiency before an ITQ regime is introduced, $r > p - AC_{L,A}(\hat{q}_{L,A})$ holds in the initial period. From the assumptions on the cost structure, there must be equal to or more than $\overline{Q}/\hat{q}_{L,A}$ fishers in total when $r = p - AC_{L,A}(\hat{q}_{L,A})$ holds. Moreover, vessel transactions/shifts take place sequentially such that one vessel transaction or shift takes place in each period. From Lemma 1, when $r > p - AC_{L,A}(\hat{q}_{L,A})$, a vessel transaction takes place, which implies that the total number of vessel decreases. Moreover, from Lemma 2, when $r \le p - AC_{L,A}(\hat{q}_{L,A})$, a small-scale fisher shifts her/his vessel to a large-scale one, which also implies that the quota price increases. Consequently, we obtain the following proposition.

**Proposition 2:** *In Case A, the social optimum is achieved at equilibrium under an ITQ regime.*

Now let us turn to Case B. First, suppose that $r > p - AC_{S,B}(\hat{q}_{S,B})$. In this case, as in Case A, $\pi_{i,B} < r\breve{q}_{i,B}$ holds whether a fisher is a seller or a buyer of quotas in the quota market (in the second stage). Each fisher of a pair, who is randomly chosen, has an incentive to offer a price that is greater than the profit of the other fisher in the first stage, because s/he expects the quota price will not change by the vessel transaction. Although one of the two fishers, who are randomly chosen, may have an incentive to shift her/his vessel type, the quota holdings ($\breve{q}_{i,A}$) do not change by vessel shifts. Therefore, the profit of the fisher is less than $r\breve{q}_{i,A}$ even after a vessel shift. The price offered by the other fisher must be more attractive to a fisher than the profit by shifting her/his own vessel type. Thus, a vessel transaction takes place, and the quota price decreases.

**Lemma 3:** *In Case B, there is no equilibrium in which the quota price is greater than* $p - AC_{S,B}(\hat{q}_{S,B})$.

Secondly, suppose that $p - AC_{L,B}(\hat{q}_{L,B}) < r \le p - AC_{S,B}(\hat{q}_{S,B})$. In this case, whether fishers are sellers or buyers of quotas in the quota market (in the second stage), $\pi_{L,B} < r\breve{q}_{L,B}$ and $\pi_{S,B} \ge r\breve{q}_{S,B}$ hold. If a large-scale fisher shifts her/his vessel to a small-scale one, s/he expects that her/his profit will be equal to or greater than $r\breve{q}_{L,B}$. Therefore, a large-scale fisher has an incentive to shift her/his vessel to a small-scale one. However, no other fisher has an incentive to offer the price which is equal to or greater than $r\breve{q}_{i,B}\,(i = L,S)$. Thus, when $p - AC_{L,B}(\hat{q}_{L,B}) < r \le p - AC_{S,B}(\hat{q}_{S,B})$, vessel shifts from large-scale vessels to small-scale ones take place. In contrast to Case A, the quota price decreases further.

Thirdly, suppose that $r \le p - AC_{L,B}(\hat{q}_{L,B})$. Similar to the previous case, no vessel transactions take place. However, from the assumption of Case B, it holds that

$$AC_{S,B}(\hat{q}_{S,B}) < AC_{L,B}(\hat{q}_{L,B}) < AC_{L,B}(q^T_{L,B}) < MC_{L,B}(q^T_{L,B}) = p - r\,.$$

Thus, whether $\breve{q}_{L,B}$ is larger or smaller than $\hat{q}_{S,B}$, a large-scale fisher expects that her/his profit will increase if s/he shifts her/his vessel to a small-scale one and catches the amount of $\hat{q}_{S,B}$. Moreover, the profit increases further if s/he chooses the amount of catch so that the marginal cost of catch is equal to the gap between the fish and quota prices. Thus, a large-scale fisher has an incentive to shift her/his vessel to a small-scale one, and the quota price decreases by the vessel shift.

**Lemma 4:** *In Case B, there is no equilibrium in which (a)* $r \le p - AC_{S,B}(\hat{q}_{S,B})$ *holds, and (b) there is one or more than one large-scale fisher.*

Because there are too many fishers in terms of efficiency before an ITQ regime is introduced, $r > p - AC_{S,B}(\hat{q}_{S,B})$ holds in the initial period. The number of total vessels decreases as vessel transactions take place. From Lemma 3, it is possible that a small-scale fisher exits from the fishery and that large-scale fishers are remaining when $r = p - AC_{S,B}(\hat{q}_{S,B})$ holds. Therefore, there are generally less than $\overline{Q}/\hat{q}_S$ fishers in total when $r = p - AC_{S,B}(\hat{q}_{S,B})$ holds. This is because the amount of catch of a large-scale fisher is greater than that of a small-scale fisher given the quota price. Moreover, from Lemma 4, when $r \le p - AC_S(\hat{q}_S)$ holds, large-scale fishers shift their own vessels to small-scale ones. This implies that the price of the quota decreases further.

**Proposition 3:** *In Case B, in general, the social optimum is not achieved at equilibrium under an ITQ regime. In particular, the number of fishers is smaller than that under the social optimum, and the quota price is lower than that under the social optimum.*

### 4.3 Discussion

The result of Case B contrasts strikingly with that of Case A. Whether the size of inefficient fishers is too large (Case B) or too small (Case A) influences the functions of an ITQ regime. We may not achieve an efficient harvesting structure such that the total harvesting cost is minimized, due to the size of inefficient fishers.

These results are also important in terms of policy implications. When the size of inefficient fishers is too large, the government has to implement other kinds of measures to achieve the efficiency of the fishery with an ITQ regime. For example, input controls, such as the restriction on vessel transactions and the encouragement of vessel shifts from larger ones to small ones, are possible candidates.

Our results become more robust with more than one pair in each period. The reason is as follows. Although each fisher is a price taker, the actual quota price is influenced by changes in the number and sizes of vessels. Also, it is clear from the results obtained above that the lower the quota price, the less incentives fishers have to make vessel transactions. “One pair in each period” implies that the turn for another pair comes after the price change due to a vessel transaction determined by the first pair. However, if two or more than two pairs are chosen in each period, more than one pair decides to make vessel transactions at the same time before the price change is observed. Therefore, it is possible that the number of vessels decreases rapidly and becomes fewer than that needed for the social optimum (long-run efficiency) even in Case A.

## 5. Extension

In this section, we consider some extensions, which we have excluded thus far to extract the essential results.

First, we have assumed that each fisher owns only one vessel. In reality, however, large-scale fishers often own more than one vessel. In such a case, even if entry barriers exist, existing fishers can purchase additional vessels. Then, the social optimum may be achieved in Case B because existing fishers increase the small-scale vessels by which their profits increase.

In this case, however, fishers must invest in new capital, which is usually costly. The fixed cost is considered to be greater when a fisher begins fishing with a new vessel than when a fisher keeps fishing with a used vessel even if s/he is an established fisher.[22] Moreover, the authorities sometimes set upper bounds of quotas owned by one fisher to avoid the concentration of quotas to a small number of fishers. Lian et al. (2010) referred to this point and investigated the harvest structure under different kinds of restrictions of quota holdings and transactions. Anderson and Bogetoft (2007) also considered the upper bound. In the presence of these types of costs and restrictions, the social optimum cannot be achieved in Case B. In this respect, it can be considered that there exists a conflict between the long-run and the short-run efficiency.

Second, there are usually switching costs, which are the costs for vessel shifts in the present context. The reason is the same as the case of new entry: a vessel shift may imply "scrapping one vessel" and "investing in a new vessel." In this case, vessel shifts are discouraged, and vessel transactions are encouraged instead.

Consider the situation in which $p - AC_{S,A}(\hat{q}_{S,A}) < r \leq p - AC_{L,A}(\hat{q}_{L,A})$ (resp. $p - AC_{L,B}(\hat{q}_{L,B}) < r \leq p - AC_{S,B}(\hat{q}_{S,B})$) holds in Case A (resp. Case B). Then, a vessel transaction can be made between the two fishers of a pair if a small-scale (resp. a large-scale) fisher does not have an incentive to shift her/his vessel to a large-scale (resp. a small-scale) one because of the switching cost. Thus, it is likely that the situation in which

22 Weninger and Just (2002) considered the cost for investment in new capital.

the number of vessels is smaller than that under the social optimum is generated even in Case A. Consequently, the switching costs make the inefficiency greater in both cases.

Third, we have assumed that fishers are price takers even when they decide on vessel transactions/shifts. Fishers, however, may expect that the quota price will change because of vessel transactions/shifts. In the following, we extend the basic analysis to the case in which fishers take into consideration only the price effect of their own vessel transactions/shifts.[23] For simplicity, we assume that the initial allocations to all small-scale vessels are the same ($\bar{q}_S$) and those to all large-scale vessels are the same ($\bar{q}_L$). Moreover, we consider the case in which $\bar{q}_L > \bar{q}_S$.

When a vessel transaction takes place, the number of total vessels decreases. Therefore, the quota price decreases as compared with the last period. In this case, sellers (resp. buyers) of quotas suffer (resp. enjoy) an additional loss (gain) from the price decrease. Therefore, in both Cases A and B, vessel transactions are encouraged as far as there are fishers who will be buyers of quotas in the quota market after their vessel transactions. On the other hand, it is possible that there exists a case in which every fisher will be a buyer of quotas in the quota market if s/he does a vessel transaction and remains in the fishery. In such a case, vessel transactions, which are needed to achieve the efficiency, are hampered even in Case A.

Moreover, the quota price increases (resp. decreases) by a vessel shift from a small-scale (resp. a large-scale) to a large-scale (resp. a small-scale). In Case A, vessel shifts from small-scales to large-scales are important for the social optimum to be achieved through an ITQ regime. The quota price, however, increases by this shift. Moreover, a fisher who changes her/his own vessel from a small-scale to a large-scale is likely to become a buyer of quotas in the quota market, because s/he is originally a small-scale fisher and owns a small amount of initial allocation. Therefore, as compared with the case in which fishers do not consider the quota price effect, this type of vessel shift is less likely to take place. In Case B,

[23] See Footnote 17.

vessel shifts from large-scale to small-scale are important for the sizes of vessels to become efficient.[24] The quota price, however, decreases by this shift. Moreover, a fisher who changes her/his own vessel from a large-scale to a small-scale is likely to become a seller of quotas in the quota market because s/he is originally a large-scale fisher and owns a large amount of initial allocation. Therefore, as compared with the case in which fishers do not take into consideration the quota price effect, this type of vessel shift is also less likely to take place.

Overall, in general, it is more difficult for the social optimum to be achieved only through an ITQ regime when fishers take into consideration the quota price effect than when they do not.

## 6. Concluding Remarks

In this paper, we have examined whether or not the social optimum (the long-run efficiency) can be achieved only through an ITQ regime. In particular, assuming the existence of heterogeneous fishers in terms of cost structure, we explicitly considered vessel transactions/shifts between fishers. Moreover, we considered two cases in terms of real situations: one in which larger vessels are more efficient and one in which smaller vessels are more efficient.

We found that when large-scale vessels are more efficient than small-scale vessels, long-run efficiency is achieved. Nevertheless, when small-scale vessels are more efficient than large-scale vessels, long-run efficiency is not achieved; the number of vessels becomes fewer than that when the total cost is minimized. Moreover, we applied the basic analysis to extended situations. We demonstrated that the similar results hold even when there are switching costs and when fishers take into consideration the effect of their own vessel transactions/shifts on the quota price. Depending on the types of regulations on quota

[24] Recall from Proposition 3 that the social optimum cannot be achieved in Case B.

holdings, the results survive the case in which vessel owners are able to own more than one vessel.

ITQ regimes are powerful tools for achieving both effective resource management and the economic efficiency of fishing activities. In fact, they have been proven to be more effective than other adopted measures. It may, however, be true that an ITQ regime for itself cannot achieve the social optimum. This fact has also been demonstrated by several studies (see, for example, Anderson (1991), Vestergaard et al. (2005), and Bergland and Pederson (2006)). In such cases, an ITQ program accompanied by other auxiliary measures, such as the encouragement of vessel shifts, can be effective.

We did not factor in the market power of fishers in the quota market, which implies that we did not consider the effects on the short-run efficiency in detail. We also did not consider the farsighted fishers who predict the sequence of vessel transactions/shifts in the future. The investigation of the long-run efficiency incorporating these additional factors is our future task.

## References

**Anderson**, Jesper L., and Peter Bogetoft (2007). Gains from quota trade: theoretical models and an application to the Danish fishery, Europ. Rev. Agr. Econ. 34, 105-127.

**Anderson,** Lee G. (1991). A note on market power in ITQ fisheries, J. Environ. Econ. Manage. 21, 291-296.

**Armstrong**, Claire W. (2008). Using history dependence to design a dynamic tradeable quota system under market imperfections, Environ. Resource Econ. 39, 447-457.

**Arnason**, Ragnar (1993). The Icelandic individual transferable quota system: a descriptive account, Marine Resource Econ. 8, 201-218.

**Bergland**, Harald, and Pedersen, P. A. (2006). Risk attitudes and individual transferable quotas, Marine Resource Econ. 21, 81-100.

**Brandt**, Sylvia (2007). Evaluating tradable property rights for natural resources: the role of strategic entry and exit, J. Econ. Behav. Organ. 63, 158-176.

**Clark**, Colin W. (2006). *The Worldwide Crisis in Fisheries -- Econmic Models and Human Behavior* --. Cambridge University Press.

**Clark**, Ian, N., Philip J. Major, and N. Mollett (1988). Development and implementation of New Zealand's ITQ management system, Marine Resource Econ. 5, 325-349.

**Danielsson**, Asgeir (2000). Efficiency of ITQs in the presence of production externalities, Marine Resource Econ. 15, 37-43.

**Dupont**, Dinae P., and R. Quentin Grafton, 2001, Multi-species individual transferable quotas: the Scotia-Fundy mobile gear groundfishery, Marine Resource Econ. 15, 205-220.

**FAO** (2006). The state of world fisheries and aquaculture 2006. Food and Agriculture Organization of the United Nations.

**FAO** (2008). The state of world fisheries and aquaculture 2008. Food and Agriculture Organization of the United Nations.

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

**Lian**, Carl, Rajesh Singh, and Quinn Weninger (2010). Fleet restructuring, rent generation, and the design of Individual Fishing Quota programs: empirical evidence from the Pacific Coast groundfish fishery, Marine Resource Econ. 24, 329-359.

**Matthiason,** Thorolfur (1996). Why fishing fleets tend to be "too big," Marine Resource Econ. 11, 173-179.

**Newell**, Richard G., James N. Sanchirico, and Suzi Kerr (2005). Fishing quotas markets, J. Environ. Econ. Manage. 49, 437-462.

**Rosendahl,** Knut Einar, and Halvor Briseid Storrøsten (2010). Emisions trading with updated allocation: effects on entry/exit and distribution, Environ. Resource Econ. Forthcoming.

**Spulber,** Daniel F. (1985). Effluent regulation and long-run optimality, J. Environ. Econ. Manage. 12, 103-116.

**Vestergaard,** N., F. Jensen, and H. P. Jorgensen (2005). Sunk cost and entry-exit decisions under individual transferable quotas: why industry restructuring is delayed, Land Econ. 81(3), 363-378.

**Weninger,** Quinn (2008). Economic benefits of management reform in the Gulf of Mexico Grouper fishery: a semi-parametric analysis, Environ. Resource Econ. 41, 479-497.

**Weninger**, Quinn (1998). Assessing efficiency gains from individual transferable quotas: an application to the Mid-Atlantic surf clam and ocean quahog fishery, Amer. J. Agr. Econ. 80, 750-764.

**Wenigner,** Quinn, and Richard Just (2002). Firm dynamics with tradable output permits, Amer. J. Agr. Econ. 84, 572-584.

## Appendix A

Let us neglect the integer problem in this and the following Appendices to capture the essence intuitively. Using (3), total differentiation of (2)' with respect to $n_i$ $(i = L, S)$ yields:

$$\frac{dTC}{dn_L} = c_L\left(q_L^*\right) + F_L - c_L' \cdot q_L^* = 0 \,, \tag{A.1}$$

$$\frac{dTC}{dn_S} = c_S\left(q_S^*\right) + F_S - c_S' \cdot q_S^* = 0 \,. \tag{A.2}$$

It is clear that each condition implies that the average cost is equal to the marginal cost for each type of fisher. From (1), it is impossible that (A.1) and (A.2) are satisfied at the same time. Thus, Proposition 1 holds.

## Appendix B

Total differentiation of (7) and (8) with respect to $n_i(i = L, S)$ yields:

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

Thus, we obtain:

$$\frac{dq_L^T}{dn_L} = -\frac{c''_S q_L^T}{\Omega}, \quad \frac{dq_S^T}{dn_L} = -\frac{c''_L q_L^T}{\Omega}, \quad \frac{dq_L^T}{dn_S} = -\frac{c''_S q_S^T}{\Omega}, \quad \frac{dq_S^T}{dn_S} = -\frac{c''_L q_S^T}{\Omega}, \tag{A.3}$$

where $\Omega = (c''_L n_S + c''_S n_L) > 0$. Note that all of them are negative. Thus, from (7) and (A.3), it is obtained that

$$\frac{dr}{dn_s} = \frac{c''_L c''_S q_S^T}{\Omega} > 0, \quad \frac{dr}{dn_L} = \frac{c''_L c''_S q_L^T}{\Omega} > 0 \tag{A.4}$$

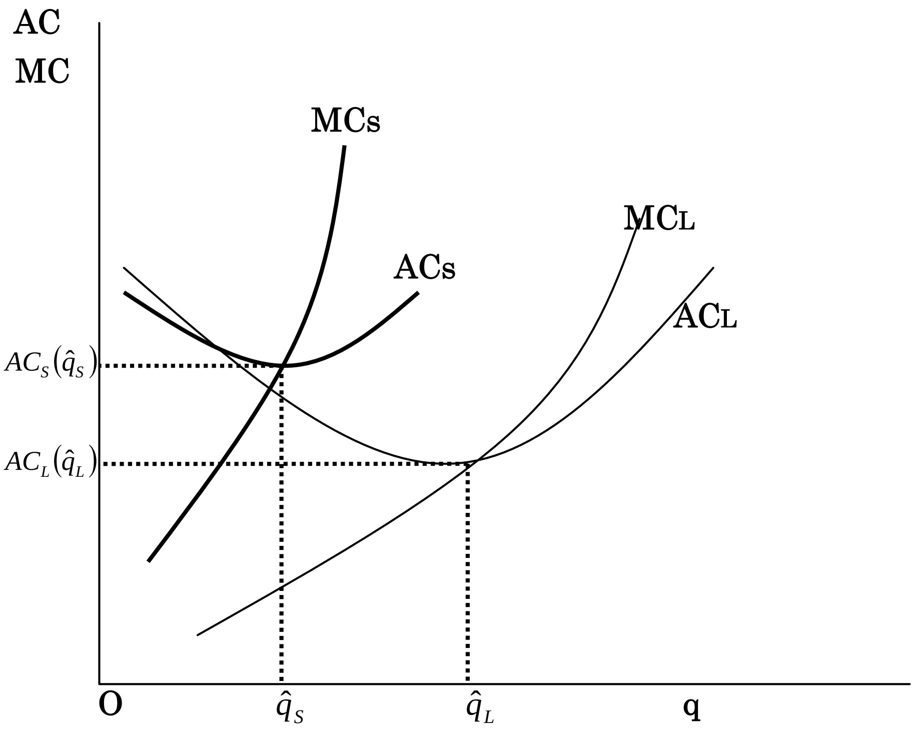


**Figure 1 (a). Cost Structure of Case A**

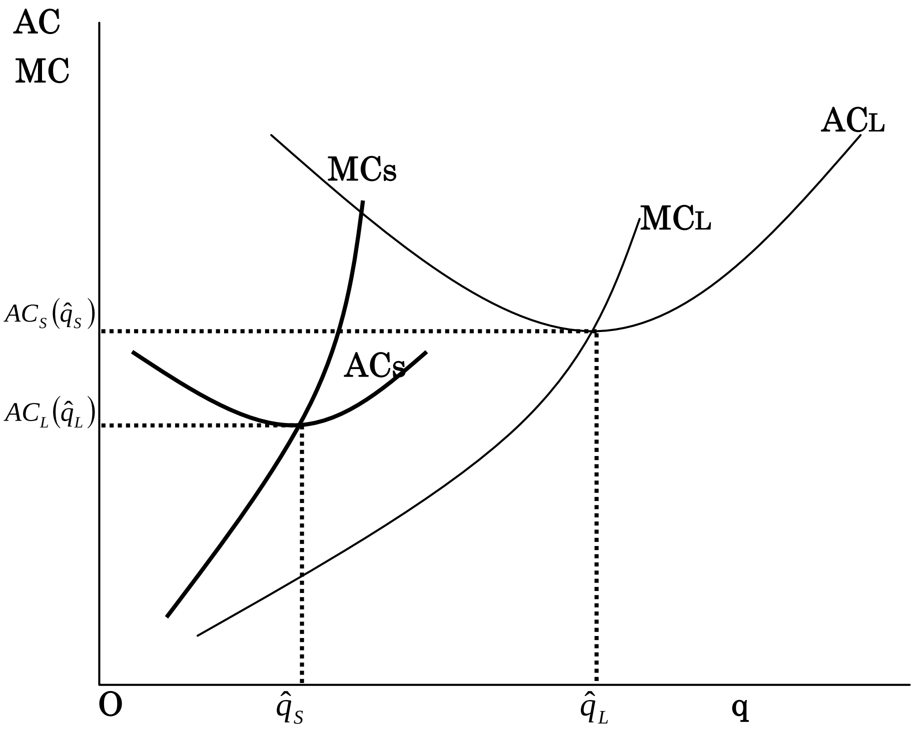


**Figure 1 (b). Cost Structure of Case B**

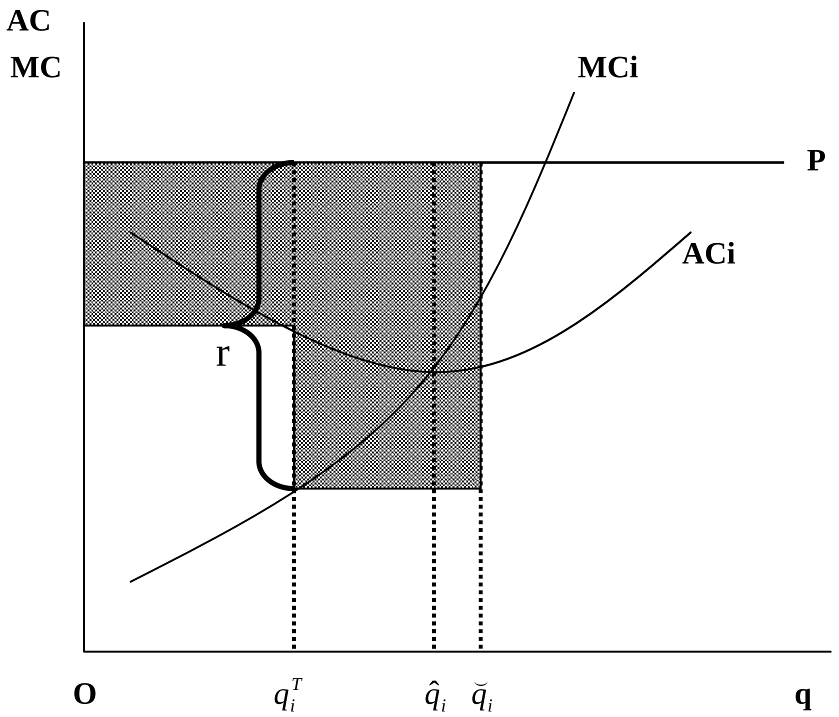


**Figure 2 (a). The profit of a fisher who is a seller of quotas in the quota market when** $r > p - AC_{L,A}\left(\hat{q}_{L,A}\right)$

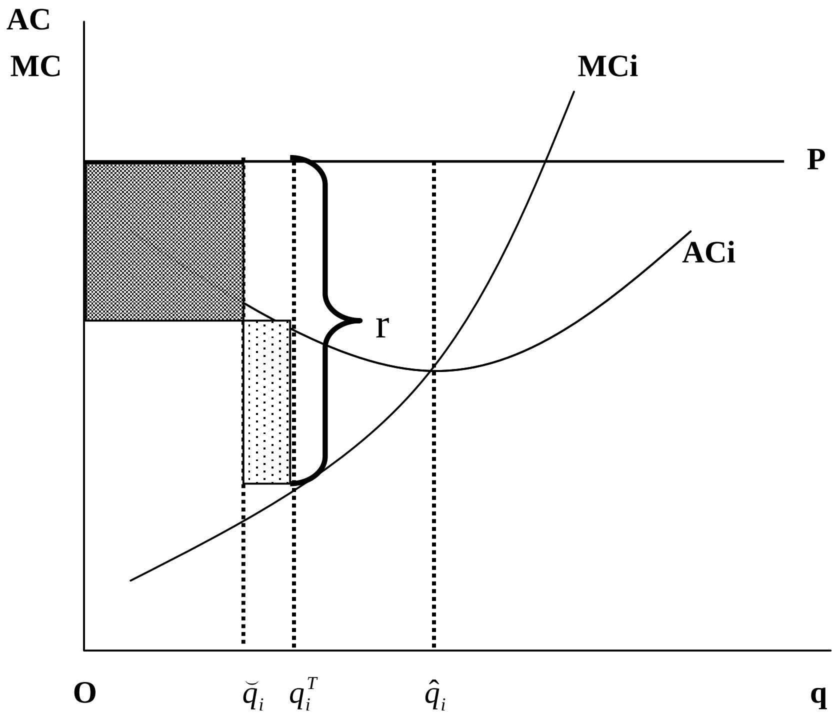


**Figure 2(b). The profit of a fisher who is a buyer of quotas in the quota market when** $r > p - AC_{L,A}\left(\hat{q}_{L,A}\right)$

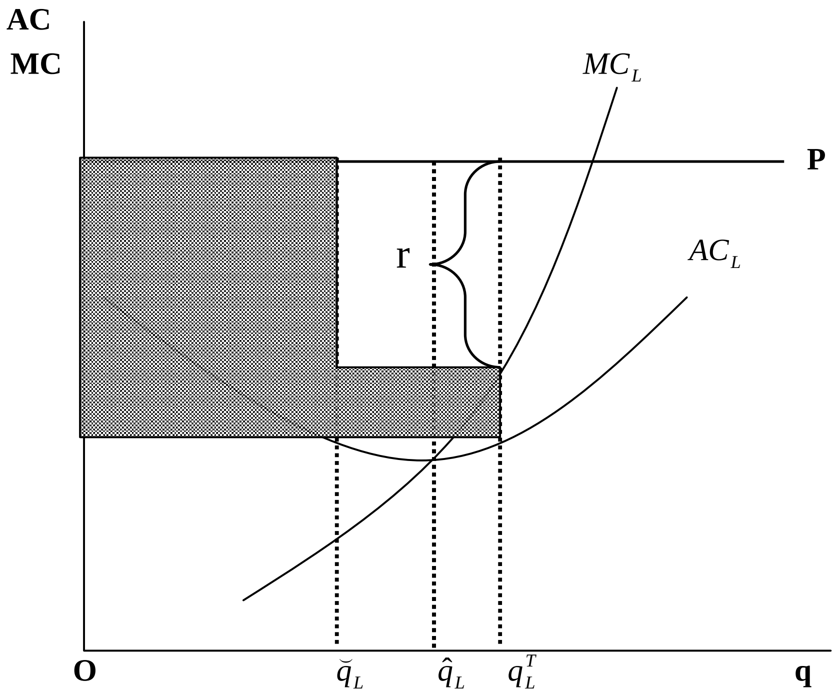


**Figure 3. The profit of a large-scale fisher who is a buyer of quotas in the quota market when** $r < p - AC_{L,A}(\hat{q}_{L,A})$