Efficiency of ITQs in the Presence of Production Externalities

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Abstract Individual transferable quotas (ITQs) are a form of property rights that can solve the inefficiencies of open-access fisheries and generate a Pareto-optimal market solution in a fishery. Some writers have pointed out that if there are some production externalities in the fishery, ITQs will not be able to generate a first-best solution. In this paper, it is argued that this is incorrect. It is proved that ITQs solve the production externalities associated with crowding, as well as the stock externality they are primarily designed to solve. In a more general setting, ITQs can form a basis for trade in the production externalities and generate a first-best solution. In this case, the contracts for transfer of quotas must include clauses that restrict further sales of quotas.

Key words Bioeconomic model, economic efficiency, fisheries management, individual transferable quotas, production externalities.

Introduction

It is generally acknowledged that ITQs can generate a Pareto-optimal economic efficiency in a fishery (Clark 1980, 1990; Neher, Arnason and Mollett 1989). Even if the property rights that ITQs give their holders are not as specific as the property rights that farmers have over their livestock, these property rights suffice to generate a first-best market solution if all markets are competitive. Some writers have pointed out that in the presence of production externalities in fisheries, ITQs would not be able to generate a first-best solution. They also contend that efforts to achieve a first-best solution with taxes requires that individual firms be taxed differently. After presenting theoretical arguments for these conclusions, Clark (1980) contends that,

[t]here is no question that severe crowding does occur in some fisheries, but in an open-access fishery, much of this crowding is probably largely due to the excess entry of vessels. If the fishery were to be managed in the general vicinity of optimality, using either fixed catch taxes, or allocated vessel quotas, it seems likely that crowding externalities would largely be eliminated—although clearly no strict conclusion of this nature is possible.

Boyce (1992) discusses the same problem and argues for the inefficiency of the ITQs in this setting with a different model. He seems to think that production externalities cause serious problems in some fisheries.

This paper argues that these conclusions are not correct. After presenting the basic model, it discusses the special case, where the level of production externalities, caused by a group of firms, is a function of their aggregate level of activity. It seems likely that production externalities, in the form of crowding, can be modelled realis-
tically by assuming that it is the sum of the activities of other firms that matters, rather than the distribution of these activities. In this case, a uniform quota market generating one uniform price for the quota generates a Pareto efficient solution.

The final section argues that ITQs can generate a first-best solution also in the more general case. If the external diseconomies (or economies in the case of positive externalities) are firm-specific; i.e., if it matters for firm $i$ if it is firm $j$ which increases its activities by one unit of harvest, or if it is firm $k$ which increases its activities by one unit of harvest, then the firms will have to add some conditions to the contracts of transfer of quotas. These conditions will be of the type: “Firm $i$ buys quota from firm $j$ and promises not to sell it to other quota holders,” and “Firm $j$ sells quota to firm $i$ and promises not to buy further quotas from other quota holders.” Such contracts between a pair of firms will involve both transfer of quotas and promises about production levels (i.e., promises about levels of externalities). In this case, the quota prices will vary.

This is, in fact, a restatement of the Coase theorem as ITQs form property rights that make it possible for firms to trade in production externalities (Coase 1960). Where no property rights exist (e.g., in fisheries where there is freedom of entry whether there is open access or a system of efficiently enforced total allowable catch [TAC]), or where the property rights are not tradable, these contracts are not possible, and the system will not generate a first-best solution.

The Model

The model in this paper is a continuous time model. These models provide a realistic description of the biological basis of the fishery, but not such a realistic description of the quota setting, as no fishery will ever be organized with momentous quotas. The choice of a model, however, is of no importance for the arguments in this paper.

Let $c_i$ denote the cost of firm $i$. Following Clark (1980), production externalities are expressed through cost functions. For the sake of simplicity, the cost functions are given here in terms of harvest levels ($h_i$) rather than effort levels. The general form of the cost functions is:

$$c_i = c_i(h_1, h_2, h_3, \ldots, h_N, x)$$

where $N$ is the number of potential firms in the industry, and $x$ is the size of the fish stock.

Set $\vec{h} = (h_1, h_2, \ldots, h_N)$. Then the problem of the social planner becomes:

$$\text{maximize } \int_0^\infty e^{-\delta t} \left[ \sum_{i=1}^N ph_i - c_i(\vec{h}, x) \right] dt$$

subject to:

$$\dot{x} = \frac{dx}{dt} = F(x) - \sum_{i=1}^N h_i$$

where $p$ is the (constant) price of one unit of fish, $\delta$ is the rate of interest, $t$ is an index of time, and $F(x)$ is the growth function of the biomass.
The current value Hamiltonian for this problem is:

\[ H = \sum_{i=1}^{N} ph_i - c_i(h_i, x) + \lambda \left[ F(x) - \sum_{i=1}^{N} h_i \right] \]  \hspace{1cm} (4)

where \( \lambda \) is the adjoint variable and indicates the social value of the natural resource.

For those firms that will participate in the industry; i.e., for those where \( h_i > 0 \) is the optimal solution, the following equation is among the necessary conditions for a maximum:

\[ \frac{\partial H}{\partial h_i} = p - \lambda - \frac{\partial c_i}{\partial h_i} - \sum_{k \neq i} \frac{\partial c_k}{\partial h_i} = 0 \]  \hspace{1cm} (5)

No Firm-specific Externalities

Production externalities, like trawlers destroying nets, or longlines and/or trawlers destroying the habitats of some species and so destroying the fishing grounds of some other fishing firms, are firm-specific. In such cases, it matters for the cost of firm \( i \) if the firm which increases its effort (i.e., buys quotas), owns a trawler or a longliner, and if the captains are reckless or not, etc. This case will be discussed below, but here, the externalities will be assumed not to be firm specific; i.e., that it does not matter for firm \( i \) which firm increases its harvest level. This seems to be a fairly realistic assumption in the case of pure crowding. In this case, the cost function of firm \( i \) is:

\[ c_i(h_i, h^e_i, x) \]  \hspace{1cm} (6)

where

\[ h^e_i = \sum_{k \neq i} h_k \]  \hspace{1cm} (7)

As \( \partial h^e_i / \partial h_i = 1, k \neq i \), equation (5) becomes in this case:

\[ \frac{\partial H}{\partial h_i} = p - \lambda - \frac{\partial c_i}{\partial h_i} - \sum_{k \neq i} \frac{\partial c_k}{\partial h_i} - \sum_{k \neq i} \frac{\partial c_k}{\partial h^e_i} = 0 \]  \hspace{1cm} (8)

In an ITQ-system where there is an efficient quota market with uniform price \( (p) \) for quotas, firm \( i \)'s objective is to:

\[ \text{maximize } \int_{0}^{\infty} e^{-\delta t} \left[ p h_i - c_i(h_i, h^e_i, x) - \sum_{k=1}^{N} \rho q_{ik} \right] dt \]  \hspace{1cm} (9)
subject to

\[ h_i = \sum_{k=1}^{N} q_{ik} \]  \hspace{1cm} (10)

and subject to

\[ h_i + h_i^c = q \]

(11)

where \( q_{ik} \) stands for the volume of quotas that firm \( i \) buys from (sells to, if \( q_{ik} < 0 \)) firm \( k \), and \( q \) is the TAC. The fisheries management authorities are assumed to take care of the stock externality through deciding the optimal TAC (\( q \)) and optimal stock level (\( x \)) in each moment of time. These values are found by solving the social planner’s problem above.

To maximize the expression in equation (9), firm \( i \) maximizes its profit \( \pi_i = ph_i - c_i(h_i, h_i^c, x) - \sum_k \rho q_{ik} \) in each moment of time. The profit-maximizing condition for firm \( i \), which participates in the fishery, \( i.e., \) decides that \( h_i > 0 \), is:

\[ \frac{\partial \pi_i}{\partial h_i} = p - \rho - \frac{\partial c_i}{\partial h_i} - \frac{\partial c_i}{\partial h_i^c} \frac{\partial h_i^c}{\partial h_i} = 0 \]  \hspace{1cm} (12)

where the last term comes from the fact that if firm \( i \) buys one unit of quota from another firm in an ITQ fishery with fixed TAC, it is also buying a decrease in that firm’s level of production. The level of production externalities from that firm will change accordingly. Previous writers, including Clark in his excellent paper (Clark 1980) have ignored this term.

Because of equation (11) \( \frac{\partial h_i^c}{\partial h_i} = -1 \), which makes it possible to rewrite equation (12) as:

\[ \frac{\partial \pi_i}{\partial h_i} = p - \rho - \frac{\partial c_i}{\partial h_i} + \frac{\partial c_i}{\partial h_i^c} = 0 \]  \hspace{1cm} (12’)

It is now possible to prove proposition 1.

**Proposition 1.** If there exists a solution to the social planner’s problem in equations (2) and (3), there are no firm-specific production externalities \( i.e., \) equations (6) and (7) are valid, the fisheries’ management chooses optimum TACs at each point in time, and there is perfect competition in all markets, then the system of ITQs generates the socially optimal solution. In this case, a uniform price of quotas will be established, and this price will induce the firms to adopt the socially optimal behavior.

**Proof:** Set the quota price

\[ \rho = \lambda + \sum_{k=1}^{N} \frac{\partial c_k}{\partial h_i^c} \]  \hspace{1cm} (13)

Substituting equation (13) into (12’) now gives:
\[
\frac{\partial \pi_i}{\partial h_i} = p - \left( \lambda + \sum_{k=1}^{N} \frac{\partial c_{ik}}{\partial h_i} \right) - \frac{\partial c_i}{\partial h_i} + \frac{\partial c_i}{\partial h_i} = p - \lambda - \frac{\partial c_i}{\partial h_i} - \sum_{k \neq i} \frac{\partial c_{ik}}{\partial h_i} = 0 \quad (14)
\]

The condition in equation (14) is exactly the same as in equation (8) in the social planner’s problem. So, if the TAC is determined by solving the social planner’s problem, then equation (14) guarantees that the ITQ system provides the socially optimal result, Q.E.D.

It is easy to see from the arguments above that a tax of \( \rho \) on each unit of harvest will also induce the firms to choose the optimal exploitation paths. The price of quotas reflects the sum of the value of the stock externality and the value of the production externality. If the externalities are all negative (i.e., they cause diseconomies, which means that \( \frac{\partial c_i}{\partial h_i} \) are all positive), then \( \rho > \lambda \).

**Firm-specific Externalities**

This section deals with the general case where the production externalities are firm specific. In an ITQ system, firm \( i \)'s objective is to:

\[
\maximize_{h_i} \int_0^\infty e^{-\lambda t} \left[ ph_i - c_i(h, x) - \sum_{k=1}^{N} \rho_{ik} q_{ik} \right] dt \quad (15)
\]

subject to

\[
h_i = \sum_{k=1}^{N} q_{ik} \quad (16)
\]

and subject to

\[
\sum_{k=1}^{N} h_k = \bar{q} \quad (17)
\]

where \( \rho_{ik} \) is the price of one unit of quota which firm \( i \) buys from firm \( k \), \( q_{ik} \) is the quantity of quotas, and \( \bar{q} \) is the optimal TAC. To maximize the expression in equation (15), firm \( i \) maximizes its profit \( \pi_i = ph_i - c_i(h, x) - \sum_{k=1}^{N} \rho_{ik} q_{ik} \) in each moment of time.

It is assumed that the firms act as price-takers. As is usually the case, the welfare results depend on the assumption that prices are not perceived as parametric in the firms’ decision problems. This assumption may be unrealistic, as it is assumed here that price is determined by the bargaining between two firms that should realize that their bargaining tactics will affect price. It should, though, be remembered that even if the firms are trading in production externalities through these bilateral contracts on quota transfers, they are at the same time trading in fishing rights, a commodity which has a much wider market.

It is also necessary to assume here that the actual volumes of externalities caused by individual vessels are independent of the quota market. If it is valuable for other vessels to decrease the fishing of some vessel, because the captain on that vessel is more reckless than others, then the price of that vessel’s quotas depends on
the captain’s recklessness, encouraging that behavior. It must be assumed here that this kind of behavior can be prevented by some other means.

If the contracts for transfer of quotas between a pair of firms involve conditional terms on buying and selling of quotas between the firms involved and all other firms in the fishery, then the conditions for profit-maximizing contracts between firm $i$ and firm $j$ are:

$$\frac{\partial \pi_i}{\partial h_i} = p - \rho_{ij} - \frac{\partial c_i}{\partial h_i} - \frac{\partial c_i}{\partial h_j} \frac{\partial h_j}{\partial h_i} = 0$$

(18)

As $i$ and $j$ are trading under the condition that they do not engage in any further trade with other firms, then $h_i + h_j = \text{constant}$, and, therefore, $\partial h_i / \partial h_j = -1$. Equation (18) can then be written as:

$$\frac{\partial \pi_i}{\partial h_i} = p - \rho_{ij} - \frac{\partial c_i}{\partial h_i} + \frac{\partial c_i}{\partial h_j} = 0$$

(18’)

For firm $j$, the same condition is:

$$\frac{\partial \pi_j}{\partial h_j} = p - \rho_{ji} - \frac{\partial c_j}{\partial h_j} + \frac{\partial c_j}{\partial h_i} = 0$$

(19)

In a market optimum where such contracts have been drawn up between all pairs of firms, the effect of one additional unit of harvest of firm $i$ must have the same effect on the cost of all other firms as one additional unit of harvest of firm $j$; i.e., the following must be valid:

$$\sum_{k \neq i, j} \frac{\partial c_k}{\partial h_i} = \sum_{k \neq i, j} \frac{\partial c_k}{\partial h_j}$$

(20)

It is now possible to prove proposition 2.

**Proposition 2.** If there exists a solution to the social planner’s problem in equations (2) and (3), the fishery is managed with optimal TACs in each moment of time, and all firms act as price-takers in all markets, then the system of ITQs can generate the socially optimal solution. To generate this solution, the contracts that the firms make concerning selling and buying of quotas must include conditions restricting further trade with other firms.

**Proof:** Let

$$\rho_{ij} = \lambda + \frac{\partial c_i}{\partial h_j} + \sum_{k \neq i} \frac{\partial c_k}{\partial h_i}$$

(21)

Substitution from equation (21) into (18’) gives:
\[ \frac{\partial \pi_i}{\partial h_i} = p - \left( \lambda + \frac{\partial c_i}{\partial h_j} + \sum_{k \neq i} \frac{\partial c_k}{\partial h_j} \right) - \frac{\partial c_i}{\partial h_i} + \frac{\partial c_j}{\partial h_j} = p - \lambda - \frac{\partial c_i}{\partial h_i} - \sum_{k \neq i} \frac{\partial c_k}{\partial h_i} = 0 \quad (22) \]

which is the same equation as (5) above.

By using equation (20), it follows directly from equations (18’) and (19) that:

\[ \rho_{ij} = \lambda + \frac{\partial c_i}{\partial h_j} + \sum_{k \neq i} \frac{\partial c_k}{\partial h_j} = \lambda + \frac{\partial c_j}{\partial h_i} + \sum_{k \neq j} \frac{\partial c_k}{\partial h_j} = \rho_{ji}, \quad \text{Q.E.D.} \]

References


