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INDIVIDUAL TRANSFERABLE QUOTAS AND PRODUCTION EXTERNALITIES IN A FISHERY

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ABSTRACT. This paper determines the conditions under which an individual transferable quota (ITQ) system will cause fishermen to engage in cost-decreasing, rather than cost-increasing, competition. If there are production externalities (e.g., congestion or stock externalities) present, the market price of a quota will not be fully reflected in these externalities. Thus, fishermen will not fully internalize the externalities in their effort decisions. Even if there are no production externalities, an individual fisherman imposes costs on others under open access by removing a fish that was available to all fishermen. An ITQ system allows the individual who values that fish most to obtain the right to harvest the fish, so each fisherman must internalize the full social cost. Thus, an ITQ system is capable of solving the common property externality but not the production externalities in a fishery.

KEY WORDS: Transferable quotas, production externalities, fishery.

1. Introduction. Open access and common property fisheries each possess the characteristic that ownership of the fish is by a "rule of capture." That is, an individual fisherman can claim ownership only by harvesting a fish. This system of property rights gives each fisherman an incentive to increase effort in order to increase his or her share of the harvest. However, if each fisherman in the fishery responds to this incentive, the result is that each fisherman has higher costs. This is commonly called the "race-for-fish" or "over-capitalization" problem. This causes fishery profits to be dissipated by the cost-increasing competition.

Cost-increasing competition occurs for several reasons. First, if the resource is common property or if access is open to all, there is the problem of the rule of capture. However, this is not the only cause of the cost-increasing competition. In many fisheries, production externalities related to the jointness in production among the fishermen also exist. Ever since Vernon Smith's work [1969] economists have spent considerable energy exploring the effects of "stock" and "congestion" externalities in fisheries. Stock externalities occur because the productivity of a unit of effort depends upon the density of the stock that is being exploited. When people are jointly harvesting from the same resource pool, an individual does not have an incentive to take into account the increase in costs to other fishermen due to his reduction in the stock density. Congestion externalities occur when the return to effort in a particular location depends upon the amount of effort being applied at that location. When choosing to participate in the location, an individual considers the effect of the congestion upon his or her own effort, but does not take into account the effect his or her participation has upon the other fishermen in the fishery.

The question economists and managers have grappled with for a number of years is how to devise a regulatory system that encourages cost-reducing, rather than cost-increasing, competition. The history of this regulation, however, includes few long-term successes (Townsend [1990]). The idea applied to the salmon industry in Alaska and in British Columbia was to limit entry. However, this merely converted an open access fishery into a common property fishery. Those who remained in the fishery continued to engage in cost-increasing competition (Wilen [1979]).[1]

Given the problems of limited entry programs, economists have turned to the idea of creating individual transferable quotas (ITQs) (Christy [1973]). Because ITQs create property rights where formerly no such rights existed, economists often conclude that ITQs will solve the over-capitalization and race-for-fish problems in a fishery (cf., Neher, et al. [1989])[2]. I argue that an ITQ system, as commonly envisioned, is capable of addressing only one of the sources of the cost-increasing competition, namely, the incentive derived from the rule of capture.

Neither a stock nor a congestion externality requires that the resource being harvested be owned by a rule of capture. These production externalities are independent of the ownership of the resource. On the other hand, cost-increasing competition will occur in a common property fishery even without production externalities because of the rule of capture. While there have been many supporters of ITQs, the only major criticism has come from Copes [1986]. Copes argues that an ITQ system will not eliminate the cost-increasing competition in a fishery characterized by production externalities. However, Copes' arguments are in conflict with earlier, more mathematical analysis, most notably by Clark [1980].

This paper presents a formal analysis of some of the arguments made by Copes. I determine how the market price for ITQ permits affects the behavior of the fishermen both with and without production externalities. In either case, relative to open access, ITQs will result in a more efficient allocation of resources. However, the conditions under which ITQs will *eliminate* the incentive for cost-increasing competition are quite restrictive. My principal conclusion is that the market price of a quota will fully reflect the social costs only if no production externalities exist. Thus, a necessary condition for an ITQ program to eliminate cost-increasing competition is that the only external cost of the harvest of a fish by one person is that no one else may now harvest the fish. If there are any other costs imposed, either by the removal of the fish or by the effort required for its removal, these costs will not be reflected in the market price for quotas and will be ignored by fishermen. These arguments are developed in Sections 2 and 3.

In addition, in Section 4 I briefly explore an alternative to ITQs that will cause fishermen to fully internalize the costs of their behavior. The idea is a blending of the ITQs idea and Anthony Scott's [1960] principle of sole ownership: I argue that if the government is going to establish property rights in a fishery, instead of establishing individual transferable rights to harvest the fish, it should create individual transferable shares in the profits of the fishery.

2. The open access problem. For most fisheries, the status quo is that of open access or common property. Furthermore, fisheries rarely are comprised of homogeneous fishermen. There are typically differences in the physical capital used, as well as differences in the human capital of the fishermen. Most mature fisheries are also managed in some fashion by government regulators. The regulation of the fishery generally includes, at a minimum, season or total harvest constraints. Within a season, the total harvest by the fleet is limited by a fleet-wide quota. Although other regulations are also often imposed, such as limits on gear types and in some cases on the number who may participate in a fishery, I ignore these differences in what follows.

A. *The social planners problem.* To examine the social costs of the open access fishery, I first examine the way the fishery would operate if managed by a benevolent social planner. The in-season optimization problem for the social planner is to choose the effort level (defined by the number of agents and the effort from each agent), and the length of the season to maximize the stream of benefits from harvesting a quantity of fish. Since I am concerned with the in-season optimization problem, the total harvest of fish is treated as exogenous.

Let the rate of harvest by the ith agent be given by the production function

$$y_i(t) = y_i(x_i(t), x_{-i}(t), s(t)).$$

The effort controlled by each fisherman at each moment t is denoted $x_i(t)$, and the production function is increasing and concave both in this argument and in the biomass $s(t)$. In addition, congestion, here measured by the aggregate effort of the other agents participating in the fishery, $x_{-i}(t)$, also enters the production function, although it has a negative first derivative.[3] Heterogeneous in the production capabilities of individual fishermen is indicated by the subscripts on the production functions, y_i.

Individuals may also be heterogeneous in their costs. There are two direct costs associated with fishing. The variable costs are given as an increasing convex function of the level of effort applied by the fisherman,

$$c_i(t) = c_i(x_i(t)).$$

In addition, each fisherman faces avoidable fixed costs of entering, K_i. Both costs may vary across individuals.

The output price P is assumed to be constant over time and, because the output quota is held constant in each model, is assumed to be exogenous. Harvesting reduces the biomass over the course of the season, and there is no in-season replenishment of the stock. Thus, the stock equation of motion is given by

$$s'(t) = -\sum_{j=1}^{N(t)} y_j(x_i(t), x_{-i}(t), s(t)), \tag{1}$$

where $N(t)$ is the number of active fishermen at time t, and y_j is the harvest per fisherman at time t. Without loss of generality, assume that $s(0) = s_0$ and that $s(T) = E$, where E denotes the biological escapement required for future harvests and T is the length of the season. E is determined exogenous to the present problem. Let $Q = s_0 - E$. Q represents the total biomass removed within the season: the fleet-wide quota. The season length is simply the time it takes to harvest the fleet-wide quota; i.e., T is the implicit solution to

$$Q = \int_0^T \sum_{j=1}^{N(t)} y_j(x_j(t), x_{-j}(t), s(t))\, dt. \tag{2}$$

Since I am concerned with the prosecution of a fishery within a particular season, I simplify the analysis by assuming that the discount rate is zero. When there are no stock effects (i.e., $\partial y_i/\partial s = 0$ for all i), a zero discount rate implies that effort is constant over the course of the season. This will not be the case if the discount rate is positive. While the assumption of a zero discount rate affects the characterization of the prosecution of the fishery, it does not affect the argument regarding the efficiency of ITQs.

The optimization problem for a benevolent social planner is to choose x_i, N and T to maximize

$$V = \int_0^T \left[\sum_{j=1}^{N(t)} P y_j(x_j(t), x_{-j}(t), s(t)) - c_j(x_j(t)) \right] dt - \sum_{j=1}^{N(0)} K_j$$

subject to the equation of motion on the biomass, (1). The variable costs depend upon both the level of effort per fisherman and the number of fishermen at each instant in time. The fixed costs depend only upon the maximum number of fishermen present. Because there is assumed to be no influx of the biological stock during the season, the maximum number of fishermen occurs at the opening of the season.

The Hamiltonian for the variable cost part of the social planner's problem is

$$H_{sp} = \sum_{j=1}^{N(t)} (P - \lambda) y_j(x_j, x_{-j}, s) - c_j(x_j),$$

where the costate variable represents the marginal value of a unit of biomass at each point in time. From the maximum principle, the first order conditions in the variables x_i, s and λ are

$$\frac{\partial H_{sp}}{\partial x_i} = 0:$$

$$(P-\lambda)\frac{\partial y_i}{\partial x_i} + (P-\lambda)\sum_{j\neq i}^{N}\frac{\partial y_j}{\partial x_{-j}}\frac{\partial x_{-j}}{\partial x_i} = \frac{\partial c_i}{\partial x_i}, \tag{3}$$

$$i = 1, \ldots, N,$$

$$\frac{\partial H_{sp}}{\partial s} = -\lambda': \qquad -\lambda' = (P-\lambda)\sum_{j=1}^{N}\frac{\partial y_j}{\partial s}, \tag{4}$$

and

$$\frac{\partial H_{sp}}{\partial \lambda} = s': \qquad s' = -\sum_{j=1}^{N} y_j(x_j, x_{-j}, s). \tag{1'}$$

The economic interpretation of these conditions is straightforward. Equation (1′) simply repeats the equation of motion for the biomass. From (3), the effort of the ith agent is chosen so that the net value of the marginal product of effort (the first term) is equated with the marginal factor cost of effort (the third term) plus the sum of the external costs imposed on other participating agents (the second term). Thus, the social planner takes into account the congestion externality in the selection of effort. Equation (4) states that the costate variable declines according to the sum of the net value of marginal production of the biomass.

In the event that the stock effect on production is zero (i.e., $\partial y_i/\partial s = 0$ for all i), then the right-hand side of (4) vanishes, implying that the costate variable is constant over time. Therefore, from (3), each individual's effort is constant. In this case, the length of time that each individual is active in the fishery would be equal. However, if there is a stock effect, (i.e., $\partial y_i/\partial s \neq 0$), then (4) implies that λ will be decreasing over time. This means that effort will not be constant. Thus, an exiting condition is required.

Following Clark [1980], agents are assumed to be ordered so that the lowest cost fishermen enter first, the next lowest second, and so forth. (This ordering may not be unique if fishermen are heterogeneous in both variable and quasi-fixed costs.) The exiting condition for the Nth individual is

$$(P-\lambda)y_N(x_N, x_{-N}, s) - c_N(x_N) = 0. \tag{5}$$

The interpretation of (5) is simply that the Nth individual exits when variable profits approach zero. The corresponding entry condition is that over the interval $(0, T_N)$ that the Nth individual is active, he must just cover the cost of entry, i.e.,

$$\int_0^{T_N} [(P-\lambda)y_N(x_N, x_{-N}, s) - c_N(x_N)]\, dt = K_N. \tag{6}$$

B. *The open access equilibrium.* Under open access, the ith individual attempts to maximize his own profits subject to the constraints of the actions of the other agents. Throughout the paper, I assume that the individuals simultaneously solve an *open loop* optimization program. The open loop assumption is made for simplicity of analysis, but it may be defended on the basis of a competitive harvesting sector.[4]

The optimization problem for the ith participating individual is to choose effort x_i to maximize

$$V_i = \int_0^T [Py_i(x_i, x_{-i}, s) - c_i(x_i)]\, dt, \qquad i = 1, \ldots, N,$$

subject to the equation of motion given by (1). The associated Hamiltonian is

$$H_i = Py_i(x_i, x_{-i}, s) - c_i(x_i) - \lambda_i \sum_{j=1}^{N(t)} y_j(x_i, x_{-i}, s), \qquad i = 1, \ldots, N.$$

The first order necessary conditions of interest are the costate equation for λ_i and the derivative of H_i with respect to effort. Assuming an open-loop Cournot solution, the necessary conditions are

$$\frac{\partial H_i}{\partial x_i} = 0: \qquad (P-\lambda_i)\frac{\partial y_i}{\partial x_i} = \lambda_i \sum_{j \neq i}^{N} \frac{\partial y_j}{\partial x_{-j}} + \frac{\partial c_i}{\partial x_i}, \qquad i = 1, \ldots, N, \tag{7}$$

and

$$\frac{\partial H_i}{\partial s} = -\lambda_i' : \qquad -\lambda_i' = (P - \lambda_i)\frac{\partial y_i}{\partial s} - \lambda_i \sum_{j \neq i}^{N} \frac{\partial y_j}{\partial s}, \qquad i = 1, \ldots, N. \tag{8}$$

A comparison of (7) and (8) with (3) and (4) reveals the open access problem. In (7) the second term is multiplied only by the imputed shadow value of the stock λ_i, whereas the same term in (3) is multiplied by $(P - \lambda)$. Thus, even if the individual's marginal valuation of the biological stock λ_i equals the social value λ, the individual still fails to take into account the reduction in revenues to the other participating agents due to the congestion externality the individual imposes on them. Similarly, in (8), the ith agent fails to take into account the gross marginal value of the biomass (P times the summation in the last term) accounted for in the social optimum in (4).

The exiting and entry equations for the marginal entrant under open access are, respectively,

$$P y_N(x_N, x_{-N}, s) - c_N(x_N) = 0, \tag{9}$$

and

$$\int_0^{T_N} [P y_N(x_N, x_{-N}, s) - c_N(x_N)]\, dt = K_N. \tag{10}$$

These conditions imply the Nth individual earns zero profits in gross over the entire planning horizon, and that at the moment of exiting is earning zero variable profits as well. The exiting condition also holds for the infra-marginal individuals. That is, at the moment that an infra-marginal entrant exits, that individual is just earning zero variable profits. However, this does not mean that they earned zero profits over the entire time horizon.

As was the case with the social planner's model in section 2A, when there are no stock effects (i.e., $\partial y_i/\partial s = 0$ for all i), all individuals will exit at the end of the season. This is because neither the costate variables nor effort varies over time when there are no stock effects.

C. *The case of no congestion or stock externalities.* One might believe that the differences in the above two systems of equations is due entirely to the congestion and stock externalities. However, a comparison of the social planner's case with the open access case when neither congestion nor in-season stock externalities exist reveals that this is incorrect. Notice from the costate equations (4) and (8) that if there are no stock effects then the costate variables are constant over the season. Thus, it follows from (3) and (7) that the effort levels of each active agent are constant over the course of the season. If effort is constant over the season, then it also follows that each active individual will participate for the entire season. Given these observations, the problem may be converted into a static optimization problem.[5]

For both the social planner and open access models, the season length constraint (2) may be rewritten as

$$Q = T\sum_{i=1}^{N} y_i(x_i). \tag{11}$$

The social planner wishes to choose the number of participants N and the effort level by each active participant x_i to maximize

$$V = T\sum_{i=1}^{N}[Py_i(x_i) - c_i(x_i)] - \sum_{i=1}^{N} K_i$$

subject to (11). The problem thus stated is linear in the season length T. For this reason, suppose that the season length has an upper bound, say $T \leq \overline{T}$. Thus the social planner's problem may be restated as[6]

$$\begin{aligned} L = T\sum_{i=1}^{N}&[Py_i(x_i) - c_i(x_i)] \\ &- \sum_{i=1}^{N} K_i + \alpha\left[Q - T\sum_{i=1}^{N} y_i\right] + \beta[\overline{T} - T]. \end{aligned}$$

Dropping the effort arguments from the notation, the first order condition for effort by the ith fisherman is

$$(P-\alpha)y_i' - c_i' = 0, \qquad \text{for } i = 1, \dots, N. \tag{12}$$

The season length equation is

$$\sum_{i=1}^{N}(P-\alpha)y_i - c_i = \beta, \tag{13}$$

where $\beta \geq 0$, $\overline{T} \geq T$, and $\beta[\overline{T}-T] = 0$.

The entry condition under the social planner's case is found by solving for the value of N that maximizes V,

$$Py_N - c_N - \alpha y_N = K_N/T. \tag{14}$$

This condition simply states that the marginal entrant must just cover the fixed costs of entry over the course of the season. It is exactly analogous to (10).

It is easy to show that the social planner will choose the season length to equal $\overline{T}$ in this model. Suppose not; then $\beta = 0$, implying the left hand side of (13) equals zero. However, from (14), the expression on the left hand side of (13) for the Nth fisherman is equal to K_N/T, which is positive. Furthermore, all other individuals in the summation have profits greater than the Nth fisherman. Thus, the summation on the left hand side of (13) cannot equal zero, implying that $\beta > 0$ and the season length equals $\overline{T}$.

Now consider the corresponding conditions for the open access situation. The season length constraint (11) still must hold, but the objective function involves only the individual agent's profits, thus

$$L_i = T[Py_i(x_i) - c_i(x_i)] - K_i + \alpha_i\left[Q - T\sum_{i=1}^{N} y_i\right] + \beta_i[\overline{T}-T].$$

Again, assuming a Cournot solution, the effort equation for the ith fisherman is

$$(P-\alpha_i)y_i' - c_i' = 0, \qquad \text{for } i = 1, \ldots, N. \tag{15}$$

Differentiating V_i with respect to T gives an equation for the season length,

$$Py_i - c_i - \alpha_i\sum_{i=1}^{N} y_i = \beta_i, \qquad \text{for } i = 1, \ldots, N. \tag{16}$$

The zero-profits entry condition for open access is (cf. (10))

$$Py_N - c_N = K_N/T. \tag{17}$$

Unlike the social optimum case, the assumption that the season length is less than $\overline{T}$ does not result in a contradiction. This suggests that the season length is shorter under the open access equilibrium than under the social optimum. This, of course, is as intuition suggests. However, while it is easy to see the differences between the two systems of equations, it does not appear possible to show in general that the season length is in fact shorter under the open access than is socially optimal.

It is possible to show that the two equilibria result in different allocations of resources. Let us compare (12) with (15). Under open access, each entrant, including the marginal entrant, ignores the full social cost of removing addition stock from the fleet-wide quota in their selection of the effort level. Arnason [1989] has shown that under optimal effort levels (solutions to (12)), the social planner's shadow value of the unharvested stock equals the *sum* of the individual shadow values from the open access model, i.e.,

$$\alpha = \sum_{i=1}^{N} \alpha_i. \tag{18}$$

In the present model, this result is possible only if there is a corresponding relationship between β and the β_i's. Using (12), (15) and (18), and assuming that $x_i^* = x_i^0$ (the solutions to (12) and (15), respectively), it follows that

$$p - c_i'/y_i' = \sum_{j=1}^{N} p - c_j'/y_j', \qquad \text{for all } i = 1, \dots, N, \tag{19}$$

which implies

$$\sum_{j \neq i}^{N} p - c_j'/y_j' = 0. \tag{20}$$

Thus, the open access cannot result in the same level of effort as under the social optimum.

A similar comparison can be made of the entry conditions (14) and (17). In (17), the costate value for the marginal entrant is zero since the marginal entrant earns zero profits for each unit of time. The entry condition for open access implies that the marginal entrant ignores the term αy_N, which is the marginal social value of the stock removed by the Nth entrant at each instant in time.

Since there are no production externalities in the present model, the misallocation of resources is due entirely to the absence of ownership of the resource.

3. Individual transferable quotas. Let us now turn to the central question of whether or not an ITQ system will cause fishermen to internalize the social costs of their behavior. Suppose that all fishermen who participated under the open access are given quota shares. Let each individual in the fishery be given a quota at the beginning of the season, $q_i(0)$, and let $q_{-i}(0)$ refer to the quotas granted to the remaining fishermen.[7] The number of quotas dispersed across the fishery satisfy

$$Q = q_i(0) + q_{-i}(0), \tag{21}$$

where Q is the total allowable harvest for the fleet. The number of outstanding or unused quotas held by the ith fisherman changes over time according to

$$q_i' = -y_i(x_i, x_{-i}, s) + z_i. \tag{22}$$

The term z_i denotes the ith fisherman's purchase ($z_i > 0$) or sale ($z_i < 0$) of quotas at each instant of time. The number of unused quotas held by the remaining $N-1$ fishermen changes over time according to

$$q_{-i}' = -\sum_{j \neq i}^{N} y_j(x_j, x_{-j}, s) - z_i. \tag{23}$$

In (23) the identity that $z_i = -z_{-i}$ is used to substitute z_i in for $-z_{-i}$. This ensures that the adding up condition for sales of quotas is satisfied. In addition, the number of quotas that may be transferred at any moment is subject to the constraints

$$-q_i(t) \leq z_i(t) \leq q_{-i}(t), \qquad \text{for } i = 1, \ldots, N. \tag{24}$$

That is, the ith fisherman can sell at most what he owns, and buy at most what remains on the market.

A. *ITQs in the presence of stock and congestion externalities.* If quotas are transferable, then in a competitive market there will exist a price for these quotas. Let $m(t)$ denote the market price of quotes. To an individual receiving an initial quota of $q_i = q_i(0)$, which may be augmented or reduced by buying or selling quotas, the objective function is to maximize

$$V_i = \int_0^T [Py_i(x_i, x_{-i}, s) - c_i(x_i) - mz_i]\, dt,$$

subject to the equations of motion for the quotas given by (22) and (23), and given the actions of the other fishermen. The associated Hamiltonian is

$$\begin{aligned} H_i = {} & (P - \nu_i)y_i(x_i, x_{-i}, s) - c_i(x_i) - mz_i \\ & - \nu_{-i}\left[\sum_{j \neq i}^{N(t)} y_j(x_j, x_{-j}, s) + z_i\right] + \nu_i z_i. \end{aligned}$$

For an active fisherman (one who does not sell all of his quota) the necessary conditions for the control variables x_i and z_i for this problem are

$$\frac{\partial H_i}{\partial x_i} = 0: \qquad (P - \nu_i)\frac{\partial y_i}{\partial x_i} = \frac{\partial c_i}{\partial x_i} + \nu_{-i}\sum_{j \neq i}^{N} \frac{\partial y_j}{\partial x_{-j}}, \qquad i = 1, \ldots, N, \tag{25}$$

and

$$\frac{\delta H_i}{\delta z_i} = 0: \qquad m = \nu_i - \nu_{-i}, \qquad i = 1, \ldots, N. \tag{26}$$

The costate equations for the quotas held by the ith fisherman and by the others use the fact that the remaining stock equals the escapement plus the outstanding quotas, i.e., $s(t) = q_i(t) + q_{-i}(t) + E$.

$$\frac{\partial H_i}{\partial q_i} = -\nu_i' : \qquad -\nu_i' = (P - \nu_i)\frac{\partial y_i}{\partial s} - \nu_{-i}\sum_{j \neq i}^{N} \frac{\partial y_j}{\partial s}, \qquad i = 1, \ldots, N \tag{27}$$

and

$$\frac{\partial H_i}{\partial q_{-i}} = -\nu_{-i'} : \qquad -\nu_{-i'} = (P - \nu_i)\frac{\partial y_i}{\partial s} - \nu_{-i}\sum_{j \neq i}^{N} \frac{\partial y_j}{\partial s}, \qquad i = 1, \ldots, N. \tag{28}$$

First, let us establish that the market price for permits remains constant over the entire season.[8] To see this, differentiate (26) with respect to time to yield

$$m' = \nu_i' - \nu_{-i}' = 0. \tag{29}$$

The second equality in (29) comes from (27) and (28). The relationship in (26) also shows that the transfer of permits will instantaneously adjust to the equilibrium value due to the 'bang-bang' nature of the control variable z_i.[9]

Recall the social planner's problem given by (3), (4) and (1′). In the event that

$$\nu_{-i} = P - \lambda, \tag{30}$$

and

$$\nu_i = \lambda, \tag{31}$$

observe that (25) and (3) are identical. Furthermore, if these conditions hold, then (27) and (28) are equivalent to (4). It is the conditions (30) and (31) that must hold if the ITQ system is to replicate the social planner's problem. Suppose these conditions hold. Substituting (30) and (31) into (26) shows that

$$m = P. \tag{33}$$

However, this cannot occur since an individual who buys a unit of the output quota still must incur the costs of harvesting the fish. Since this is a positive cost, the market price for permits must be less than P. This implies the following:

THEOREM ONE. An ITQ system in which transferable quotas allocated at the beginning of the season are traded at a competitive market price is not capable of simultaneously solving the in-season stock externality problem and the congestion externality problem.

Theorem One shows that individual transferable quota programs do not work to cause fishermen to fully internalize the costs of their actions in the presence of stock and congestion externalities. The intuition behind the result is fairly simple. Since the property right associated with a quota of the output carries with it no time specification nor a right to catch fish in an uncongested fishery, there remains a fundamental diseconomy. Even if ITQs are put into place, a race for fish and overcapitalization of the fishery will continue to persist.

It should come as no surprise that an ITQ system is not able to deal with the congestion externality problem, since this result has already been obtained by Clark [1980]. Clark's result in regards to congestion externalities has not been widely discussed, although almost every paper on fisheries ITQs references his paper. Clark, himself, discounted this finding, claiming that congestion externalities probably did not occur in a significant number of fisheries. Of course, whether this is so is an empirical question. Clark obtained his result by assuming that there were no in-season stock externalities. His result is a corollary to Theorem One.

COROLLARY ONE. In the case where only a congestion externality exists, ITQs are not capable of reproducing the social optimum.

PROOF. If only a congestion externality exists, in the system of equations (25)–(28), equations (25) and (26) are unchanged, and equations (27) and (28) each have zero right-hand sides. Again, the relationship that must hold for the market price to fully reflect the social cost of the stock is that equations (30) and (31) hold. Thus, the same problem exists: the market price for *in situ* quotas cannot equal the market price for the harvested output. □

Clark claims, incorrectly, that when the sole production externality is an in-season stock externality, ITQs are capable of solving the social optimization program. The proof is a corollary to Theorem One.

COROLLARY TWO. In the case where only a stock externality exists, ITQs are not capable of reproducing the social optimum.

PROOF. If no congestion externality exists, then (25) becomes

$$(P - \nu_i)\frac{\partial y_i}{\partial x_i} = \frac{\partial c_i}{\partial x_i}.$$

All other equations in the system (25)–(28) remain unaltered. Now, suppose that (30) and (31) hold. Again, the quota system would replicate the social optimal system. However, the same problem exists as in Theorem One: the market quota price cannot equal the output price.

Clark's error appears to be in his analysis of equations (25) and (26). While (25) differs from (3) only in that λ in (3) is replaced by v_i in (25), this result is because $\partial y_j/\partial x_{-j} = 0$, not because $v_{-i} = 0$. Thus, $v_i \neq m$. A similar mistake was made by Moloney and Pearse [1979]. However, their claim that ITQs are capable of reducing the social costs of harvesting are correct for the in-season case (which they did not consider), as will be shown in the next section.

B. ITQs *when no congestion or stock externalities exist.* If there are no stock or congestion externalities, ITQs can generate efficient incentives. To see this, consider the system (25)–(28) when no stock or congestion externalities exist:

$$(25) \qquad (P - v_i)\frac{\partial y_i}{\partial x_i} = \frac{\partial c_i}{\partial x_i}, \qquad i = 1, \dots, N,$$

$$(26) \qquad m = v_i - v_{-r}, \qquad i = 1, \dots, N,$$

$$(27) \qquad v_{i'} = 0, \qquad i = 1, \ldots, N,$$

$$(28) \qquad v_{-i'} = 0, \qquad i = 1, \ldots, N.$$

Consider the shadow values for the two different quotas. The quotas by the fisherman have value to him ($v_i > 0$) because of the profits he may obtain when he harvests his quota and sells his permits on the market. However, by assumption, the remaining stock does not affect the profitability of a fisherman of catching his remaining quota. Therefore, quotas owned by other fishermen do not affect his profits except through his purchases or sales of quotas. This implies that $v_{-i} = 0$. Using (26), we have that $m = v_i$, for all $i = 1, \ldots, N$. It follows that the market price reflects the social value of the stock as long as the market is efficient. Thus we have

THEOREM TWO. When there are no in-season stock externalities and no congestion externalities, then an ITQ system will be capable of generating social efficiency.

It is interesting to examine the entry condition under an ITQ system. The entry condition is

$$(34) \qquad \bar{T}[(P - m)y_N - c_N] = K_N.$$

The relationship in (34) can be seen as follows. The permits the fisherman owns could be sold at price m on the market. Thus all harvesting of the fisherman's own permits yields net revenues of $P - m$ per unit harvest. Similarly, for quotas the fisherman purchases, the cost of purchase must be subtracted from the revenues. Thus the net revenues are $P - m$ per unit harvest. The marginal fisherman will earn in net what it costs him to fish. However, this is the return *above* the windfall from being endowed the initial quotas. The proof that the marginal fisherman will utilize the entire season available to him is identical to the argument following equations (12)—(14).[10]

C. *Second-best effects.* The results of Theorems One and Two imply the only case in which an ITQ system is capable of generating the first-best solution is when neither in-season stock nor congestion externalities exist. However, some combination of these conditions probably exist in most fisheries. Thus, the question is whether or not there is an improvement over the open access case. The answer is yes, though it is not clear what the magnitude of this improvement is.

Suppose that each fisherman's initial quota were exactly the same share of the fleet-wide quota they would receive under common property. Then it is possible that each fisherman could act exactly as before the ITQ system was implemented. If so, then they would earn exactly the same rents as under open access. However, if any fisherman could improve his situation either by holding off on harvesting his share of the quota, or by buying a portion of shares from another, or selling part of his own share, then the ITQ system allows him to do this. Furthermore, any trade that occurs has to result in either a decrease in congestion or (possibly and) a decrease in the quantity of fish caught some time during the season.[11] Thus all other fishermen must also benefit by this trade. This implies:

THEOREM THREE. ITQs will result in an improvement over the open access equilibrium.

The question that remains is how much of an improvement over open access is an ITQ system when production externalities exist? Unfortunately, there does not appear to be a simple answer to this question. The system of equations describing the equilibrium in the presence of ITQs does not admit a simple closed form solution for any of the variables of interest. Thus, although there will be an incentive for fewer fishermen to participate than under open access, it is not clear how many fewer fishermen will be active. The empirical evidence is also mixed. While some fisheries have witnessed large reductions in effort, others have had almost no effect (Muse and Schelle [1989], Neher et al. [1989]).

4. Discussion of the results. The results derived above suggest that economists should be careful in advocating programs that assign property rights to natural resources. Property rights are very important—there seems little doubt about this. However, it does not follows that all property rights systems yield the same social results. In the case of fisheries, a system that assigns property rights to the harvestable output will generate the social optimal conditions if, and only if, the sole source of the externality is due to ownership by rule of capture. If the external costs an individual can impose on others are due to production externalities, then an ITQ system will not be sufficient to obtain the social optimum.

The second-best results suggest that ITQs will result in an improvement over an open access or common property situation. However, Theorems One and Two show that the conditions under which an ITQ system will eliminate cost-increasing competition are quite restrictive. The question of how much improvement will occur under an ITQ system is an empirical question, and one that does not seem to have been adequately studied. This alone should lead economists to be cautious in advocating ITQ programs for fisheries where production externalities are present. As Anthony Scott has noted, institutional changes are costly. Much effort is squandered if the degree of change is relatively small.

Furthermore, the preoccupation in the economics literature with congestion and stock externalities is probably not based purely on theoretical interest. It seems safe to say that these are real phenomena. This suggests property rights should be assigned in a way that takes into account the production diseconomies. The simplest and most direct way to do this is to assign *shares in the profits* from the fishery, i.e., to make the fishermen stockholders in the fishery. If fishermen have shares to the profits, they will be forced to internalize the production diseconomies. If the shareholders have control over effort allocations, they will be motivated to insure that these allocations are efficient. If property rights are assigned to shares of profits, it would require that effort be compensated separately from the compensation of fishery profits shares. Fishermen who are more productive would have to be compensated for their productivity.

This is a restatement of Anthony Scott's [1960] argument about the advantages of sole ownership. The only difference is that the sole ownership is in the hands of a corporation whose (initial) members happen to be the original fishermen. An interesting feature of this approach is how it addresses the problem identified by Karpoff [1987]. Karpoff argued that fisheries regulations are politically acceptable if they do not decrease the number of participants in the fishery. He observed that fishermen prefer regulations that increase employment in the fishery. If the fishermen have transferable shares of the profits to the fishery, then it is possible for them to choose to continue with the same quantity of effort levels as under an open access. However, if they choose employment over profits by encouraging over-capitalization of the fishery, then their choice is, by definition, the social optimum. The reason is that in choosing such an institution (if they do so), they are explicitly choosing to value the employment aspect of the fishery higher than the returns to the fishery. Since the cost of this decision is born entirely by the stockholders who are making the decision, there is no externality. Of course, in the long run, selecting to allow dissipation of the rents should not be expected to occur as long as the shares are transferable.

However, there are both historical and legal problems with ownership of profits being the transferable right. First, as noted by Johnson and Libecap [1982], the Department of Justice has not looked favorably on "monopoly ownership" of fisheries resources. However, most fisheries tend to have very elastic demand for their products. This is true even for fisheries as large as the Alaska salmon fishery. Thus, such criticisms might be overcome in a court of law.

However, a second issue is more difficult to overcome. Historically, especially on the west coast, fisheries were developed by financiers and entrepreneurs who do not live in the local fishing communities. As a result, there has been a mistrust of any scheme that might allow these "outside interests" to obtain control over a fishery.[12] This indicates that there would likely be political opposition to a plan allowing the transfer of ownership to persons outside the fishery. However, this is the same complaint that fishermen have had with regard to ITQs. The difference between shares to profits and shares to the harvest is that fishermen will not *also* oppose the stockholder version of ownership on the grounds that it does not solve the race for fish problem or the over-capitalization problem. Furthermore, even if the ownership shares leave the fishery, the labor market will likely remain.

Finally, granting fishermen property rights to the profits to the fishery, rather than to the quantity of fish they can remove, carries with it the problem of organizational costs. Currently there are almost no costs of running the fishery other than those incurred by regulators.

Under an ITQ system, there would be organization costs only in the transfer of quota permits. Under a corporate fishing fleet, there would be organizational costs that the fishermen themselves would have to incur. On the fact of it, this may appear to be the reason that cooperative arrangements have not been constructed very often in the past.[13] However, as Johnson and Libecap [1982] note, organization costs, even on large fisheries such as the shrimp fishery in the Gulf of Mexico, have not prevented fishermen from developing cooperative agreements. That distinction lies with the Justice Department's use of anti-trust statutes.

Economists have long been enamored with the institution of private property. This, of course, is justly so—no other institution is as capable of causing the individual to internalize social values as is the institution of private property. However, the "creation of property rights," as remarked upon by Anthony Scott [1989, p. 290], "is not something that even monarchs can take lightly." It is important that when economists advocate institutions that create property rights, such as ITQs, that they understand the full ramifications of their proposal. I have shown that while ITQs can solve one type of open access problem in a fishery, it will fall short of eliminating cost-increasing behavior if there exist production externalities. Furthermore, it appears that an alternative property rights system exists which is capable of eliminating cost-increasing competition even in the presence of production externalities.

ENDNOTES

* This paper has benefited from discussions with Diane Bischak, Greg Goering, Bob Logan, and by comments from an anonymous referee. All remaining errors are my own.

1. In Alaska, the state-funded enhancement program, which put more fish into the water, obscured the failure to reduce cost-increasing competition. For a number of years, the increase in quantity increased revenues at a greater rate than the increases in costs due to the cost-increasing competition. However, it appears now that further increases in fish may decrease revenues. Thus, with cost-increasing competition also occurring, the fisheries cannot continue to obtain the same profits as in the past.

2. ITQ programs have in fact been established in several fisheries with varying degrees of success (Muse and Schelle [1989]). In Canada, an ITQ system was recently instituted for the halibut fishery, and in the United States, proposals are rapidly working their way through the bureaucratic system for ITQ programs in the halibut and black cod (sablefish) fisheries in Alaska.

3. The notation x_{-i} denotes $\sum_{j \neq i}^{N} x_j$, where the summation is over $j = 1, \ldots, N$, for j not equal to i. It follows that $\partial x_{-j}/\partial x_i = 1$, for all $j \neq i$. The use of x_{-i} as a measure of the crowding variable rather than using $x = \sum_{i=1}^{N} x_i$ is a matter of convenience in notation. None of the results are affected by leaving the ith agent's effort out of this argument. However, the interpretation as a crowding variable is somewhat altered. Here, the derivative of y_i with respect to the x_{-i} variable simply denotes the effect upon the ith agent's production by the effort of the other agents participating in the fishery.

4. An alternative equilibrium concept is a closed loop or feedback method. The feedback method has the advantage of being subgame perfect, meaning that agents do not commit to a strategy which they may later regret. The closed loop equilibrium conditions involve an extra term in the costate equation which is, roughly speaking, a conjectural variation term (Negri, [1989]). However, when the number of agents is very large, this term diminishes in value. Thus, although the open loop method does not satisfy subgame perfection in a competitive environment, this is unlikely to cause a difference in the equilibrium paths (Eswaran and Lewis [1985]). Furthermore, Negri [1989] has shown that in the case of renewable ground water models, the feedback solution results in a lower steady state stock than occurs under the open loop equilibrium; thus, the closed loop equilibrium is worse than the open loop feedback. In what follows, we show that the market price for an ITQ cannot eliminate cost-increasing behavior in the presence of production externalities under the assumption of open loop optimization behavior. Since the market price does not cause cost increasing behavior to disappear in this model, it is doubtful that it will work in a model where agents are assumed to be acting more strategically.

5. The reason we convert these problems into static optimization problems is the fixed cost terms. In order to solve for the entry condition in a dynamic problem, we would need to introduce a scrap value function $\sum_{i=1}^{N} K_i$, which contains the control variable N. In order to use the standard results from optimal control theory, we would need to create another state variable measure of the number of vessels which entered the fishery. It is much simpler to turn the problem into a static optimization problem.

6. The multiplier α is analogous to the multiplier λ in the discussion in Section 2A.

7. We are making no assumption about how the quotas are handed out to fishermen. This allocation problem is extremely relevant in terms of allocation of economic rents, but is irrelevant in terms of efficiency (see Johnston and Libecap [1982]).

8. If the discount rate within the season is rate r, then the market price for permits will rise at the rate of interest over the course of the season. A positive discount rate will also imply that even in the case where there is no stock effect (i.e., $\partial y_i/\partial s = 0$ for all i), effort will not be constant over the course of the season.

9. The reader will note that I have not given an explicit statement regarding the optimal number of permits to be traded. The purpose of the model is to show that the market price cannot solve the externality problems. Thus, the actual number of permits traded by an individual is incidental to the problem.

10. In the case of no congestion or stock externalities, the objective function above (15) would be rewritten as

$$V_i = T[Py_i - c_i - mz_i] - K_i + \lambda_i[q_i(0) - T(y_i - z_i)] + \alpha[\overline{T} - T].$$

11. The reason is that there are diminishing returns to effort, so a consolidation of effort has to decrease both the catch and the number of vessels. Both decreases benefit the other fishermen.

12. In Alaska, for example, the early salmon fisheries were dominated by the owners of fish traps. Fish traps were efficient means of catching salmon. The cannery would be located at the first point on a river where it was economical to construct an obstruction across the river. The owners would build a weir that funneled the migrating fish into holding pends where the cannery workers could easily catch them and immediately put them into the processing lines or could store them at low cost during times when the run exceeded the plant capacity. The system allowed for strict control over escapement. However, the fish traps were also an effective means for excluding competitors. Since there was only room for one fish trap per river system, the cannery getting the best spot near the mouth of the river could effectively exclude all other users. Other methods of harvesting were more expensive than using the fish trap. The result was that from the 1920s through the 1950s, the fish trap technology was the dominant means of catching salmon. In practice, this meant that non-Alaska canneries were able to exclude Alaska fishermen from the market. The result was tremendous political pressure to outlaw fish traps. By 1956, when the Alaska State Constitution was drawn up, fish traps were declared illegal. Indeed, one of the main reasons for the Statehood movement was the desire to eliminate the fish traps (Cooley [1963]).

13. There is one contemporary example of which I am aware where fishermen have actually engaged in a profit sharing arrangement. In a herring fishery occurring in the Sitka Sound in Alaska, the fishermen have been organized for several years to share the profits and to restrict the number of vessels actually fishing.

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