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On Selectivity and Discarding in an ITQ Fishery

Research Project
Discarding of catch at Sea

Working Paper #1
August 1996

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0. Introduction

The available theory on discarding of catch at sea (see Anderson, 1994, Arnason 1994) demonstrates that an unmodified application of the ITQ fisheries management system induces an incentive for discarding of fish in excess of what is socially optimal. An unmanaged fishery, on the other hand, would discard in a socially optimal way. Thus, at first glance, the theory seems to suggest that an ITQ-managed fishery results in increased discards compared to an unmanaged fishery.

This note is concerned with this particular inference. More precisely, it attempts to compare the profit maximizing level of discards in an unmanaged fishery and an ITQ fishery. The basic result is that there is no simple relationship between discards and these two fisheries management systems. Discards may either increase or decrease as a consequence of the introduction of an ITQ system compared to a previously unmanaged fishery. Consequently, the supposition that an ITQ-managed fishery can only result in increased discards compared to an unmanaged fishery is unwarranted.

This result does not contradict earlier studies in the field (Anderson, 1994 and Arnason, 1994). The results derived in these studies only dealt with the decision to discard fish already caught. Thus, in these studies, the harvesting technology was taken as exogenous. In particular, fishing gear selectivity or fishing ground selection were not regarded as control variables in the harvesting process. It is precisely these variables or harvesting selectivity in general that causes the ambiguity alluded to above.

It is not difficult to show that different fisheries management systems will generally affect the profit maximizing choice of harvesting selectivity. At the same time only harvested fish can be discarded. Hence, although the tendency to discard harvested fish may increase under an ITQ fisheries management system, the impact of the same system on harvesting selectivity may actually lead to a reduction in the total volume of discards.

1. Discarding Theory

Following the discarding model developed by Arnason (1994) let there be I economic grades of fish. Refer to catch of grade i as $y(i)$, i=1,2,..I. Aggregation of catch over grades yields total catch as $y \equiv \Sigma_i y(i)$.

Let instantaneous harvesting be determined by the following strictly increasing, jointly concave harvesting function:

(1) $y \equiv \Sigma_i\, y(i) = \Sigma_i Y(e,x,i)$, for all i and $e,x \geq 0$, $Y(0,x,i)=Y(e,0,i)=0$

where the variable x represents aggregate biomass and e fishing effort. This is assumed to be undifferentiated by grades.

Harvesting costs are given by the strictly increasing convex cost function:

(2) $CE(e)$, for $e \geq 0$, $CE(0) \geq 0$.

Landings of fish of grade i are defined as the difference between harvest and discards:

(3) $l(i) \equiv Y(e,x,i)-d(i)$,

where $Y(e,x,i)$ represents the harvest of grade i as specified above, $l(i)$ retained or landed harvest and $d(i)$ the discarded harvest of grade i. It is further assumed that

$d(i), l(i) \geq 0$, all i.

There would generally be economic costs associated with landings and discarding. Let us represent those by the nondecreasing, convex cost functions:

(4) $CL(l(i),i)$, for $l(i) \geq 0$, all i, $CL(0) \geq 0$,

(5) $CD(d(i),i)$, for $d(i) \geq 0$, all i, $CD(0) \geq 0$.

The $CL(\,)$ functions represent various costs associated with retaining catch of grade i and landing it. These costs include the cost of preliminary fish processing aboard the vessel; handling, gutting, storing, preserving etc., as well as the actual landing costs.

The $CD(\,)$ functions represent the costs associated with discarding of fish of grade i. As discarding is generally relatively easy, these costs would in most cases be small. Notice, however, that if discarding is illegal or socially frowned upon, discarding costs would tend to be correspondingly higher.

Given the specifications in (1) to (5) we may write the instantaneous profit function of a given firm in the fishery as:

$$\pi\,(e,\boldsymbol{d};x;\boldsymbol{p}) = \Sigma_i\, p(i)\cdot l(i)\text{-}CE(e)\text{-}\ \Sigma_i CL(l(i),i))\text{-}\ \Sigma_i CD(d(i),i),$$

where $p(i)$ denotes the price of one unit of landings. The (1xI) vectors $\boldsymbol{d}$ and $\boldsymbol{p}$ represent discarding and quay prices of different grades of fish, respectively. In this profit function, fishing effort, e, and discarding, $\boldsymbol{d}$, are natural control variables. Biomass, x, is a state variable and the fish prices, $p(i)$, are parameters.

Maximizing the profit function with respect to fishing effort, e, and the vector of discards, $\boldsymbol{d}$, yields the following socially optimal discarding rule:

$$d(i)>0 \text{ if } p(i)+CD_d(0,i)<CL_l(Y(e,x,i)\text{-}0,i)$$

The left-hand-side of the second inequality of the discarding rule, namely $p(i)+CD_d(0,i)$, represents the marginal costs of discarding. This cost consists of two parts; the unit price of landed catch foregone by discarding, $p(i)$, and the direct marginal costs of discarding evaluated at zero discarding, *i.e.*, $CD_d(0)$. The right-hand-side of (8), $CL_l(Y(e,x,i)\text{-}0,i)$, represents the marginal benefits of discarding (or marginal costs of retaining) catch also evaluated at zero discarding. Thus, the discarding rule expressed in (8) is very simple. Catch of grade i should be discarded, i.e., $d(i)>0$, if the marginal benefits of discarding exceed the costs.

To facilitate the analysis it is convenient to define the discarding function for fish of grade i:

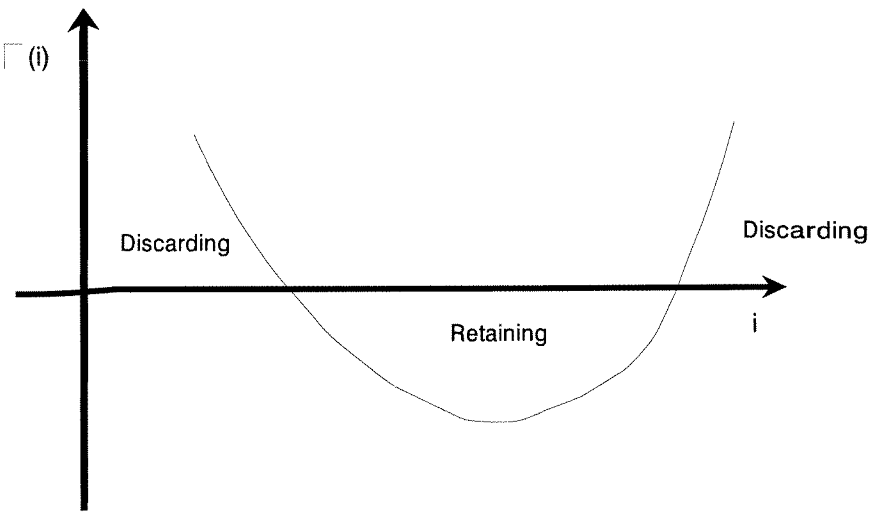
(6) $\quad \Gamma\,(i)=CL_l(y(i)\text{-}0,i)\text{-}p(i)\text{-}CD_d(0,i)$

The left-hand-side of (6), $\Gamma(i)$, is the discarding value for fish of grade i. If the discarding value for a particular grade is positive, marginal catch of that grade is discarded. If $\Gamma(i)$ is negative, catch of grade i is retained. The discarding function is not equivalent to the quantity discarded. It may, on the other hand, be interpreted as the tendency to discard.

The discarding function shows that the optimal decision to discard depends directly on (a) the quay price, (b) the marginal landing costs and (c) the marginal discarding costs of the grade in question. It seems empirically likely that $CL_l(y(i)\text{-}0)$ is increasing in the catch rate, $y(i)$, at least for $y(i)$ above a certain level. In that case, the discarding function implies that the tendency to discard increases with the catch rate. This, in fact, appears economically plausible. Moreover, as catch increases monotonously with biomass and fishing effort, the tendency to discard also generally increases with these variables, *ceteris paribus*. On the other hand, the tendency to discard a particular grade diminishes with the price of catch, $p(i)$, and the marginal cost of discarding, $CD_d(0)$. This also appears economically plausible.

The discarding function as a function of grades may in principle have any shape. One example is illustrated in Figure 1.

Figure 1
An example of a discarding function



For concreteness, the grades in Figure 1 may be thought of as fish size. The discarding function drawn suggests discarding at small and large sizes with catch being retained for middle sized fish.

Within the confines of this model Arnason (1994) showed that the discarding function for an unmanaged fishery was identical to the socially optimal one while the one for an ITQ-managed fishery was uniformly higher. More precisely, the discarding function for the ITQ-managed fishery was found to be:

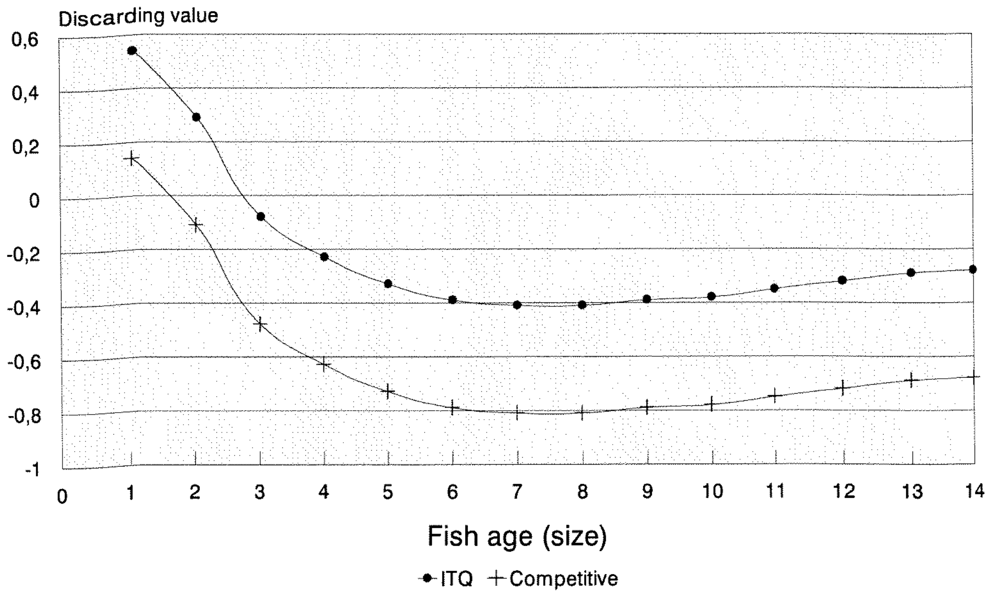
(7) $\Gamma^{\circ}(i)=CL_l(y(i)\text{-}0,i)-p(i)-CD_d(0,i)+\Omega=\Gamma(i)+\Omega,$

where $\Gamma^{\circ}(i)$ is the discarding value for the ITQ-managed fishery and $\Gamma(i)$ the discarding value for the unmanaged fishery as defined in (6) above. The difference between the two is Ω which represents the user cost of quota for the species in question. This user cost would generally be represented by the market rental price for quota which would, in commercial fisheries, invariably be nonnegative and usually strictly positive.

It is not difficult to understand the reason why the ITQ discarding function dominates the one for an unmanaged fishery. For a particular fish to be retained by a vessel in an ITQ fishery, the landed price plus the discarding cost must not only exceed the cost of landing but also the quota user cost incurred at the time of landing. Therefore, provided the quota price is positive the discarding value in an ITQ fishery is always larger.

The difference between the discarding function for an unmanaged fishery and the one for an ITQ managed fishery may be illustrated by the following figured based on the Icelandic cod fishery.

Figure 2
Discarding functions for two management regimes: A stylized version of the Icelandic cod fishery



As shown in Figure 2, the ITQ discarding function strictly dominates the unmanaged one. In fact the difference is quite pronounced. Nevertheless there is very little tendency to discard in both systems. Due to the harvesting selectivity (gear selectivity and fishing ground closures) very few cod younger than 3 years are actually caught. Consequently, there is little tendency to discard even under the ITQ system.

2. Selectivity

Let us now assume that the fishing technology allows a degree of selectivity over grades of fish at some costs.[1] For this purpose define a selectivity parameter for grade i, $a(i)$, and the corresponding cost function $CS(a(i),i)$. It is convenient to take $a(i)$ belongs to the closed interval [0,1], where $a(i)$ represents no selectivity and $a(i)$=1 full selectivity.

In accordance with this, let the harvesting function for fish of grade i be represented by:

$$y(i)=Y(e,x,i)\cdot(1-a(i))$$

where as before e denotes fishing effort, x the biomass level and $a(i)$ a selectivity parameter for grade i. $Y(e,x,i)$ is what may be referred to as the "unselective" harvesting function for fish of grade i and $(1-a(i))$ represents the harvesting modifications due to selectivity measures. Clearly, when $a(i)=0$ unselective harvesting applies and when $a(i)=1$ there is full selectivity in the sense that no fish of grade i will be caught.

The selectivity cost functions, $CS(a(i),i)$, $i=1,2,...I$, are naturally increasing and convex in the selectivity parameter, i.e., $CS_a(i)>0$, $CS_{aa}(i)>0$.

As before let us represent effort costs by the function $CE(e)$ and discarding costs by the function $CD(d(i))$ where it is assumed that both functions are increasing and convex.

In what follows it is notationally convenient to refer to the net price of catch of grade i by $P(i)$ where $P(i)$ is the per unit landings price net of all costs related to the volume of landings including handling, storage and landings costs and, as the case may be, quota values forfeited by landings. More precisely:

$$P(i) \equiv p(i)-CL_l(l(i))-\Omega,\ i=1,2,....I.$$

where as before $p(i)$ represents the gross landing price, $CL(l(i))$ the unit cost of landings and Ω the opportunity cost of quota.

Under most ITQ-based systems the opportunity cost of quotas manifests itself at the instance of landings when the volume of landed catch is debited against quota holdings. In an unmanaged fishery this opportunity cost, Ω is, of course, identically zero. In a fully fledged ITQ system Ω would be measured by the market price of quotas at the time of landings.

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1 This could be due to variable fishing gear selectivity and the choice of fishing grounds and fishing seasons.

Given all this we can define a profit function for firm j as:

$$\pi(j) = \Sigma_i P(i) \cdot [Y(e,x,i) \cdot (1-a(i))-d(i)] - CE(e) - \Sigma_i CD(d(i),i) - \Sigma_i CS(a(i),i)$$

Maximization of this profit function w.r.t. fishing effort, discards and selectivity yields the following set of necessary conditions:[2]

$\Sigma_i P(i) \cdot Y_e \cdot (1-a(i))=CE_e$, assuming $e>0$.

$-P(i)$ ó $CD_{d(i)}$, $d(i) \geq 0$, $d(i) \cdot (-P(i) - CD_{d(i)}) = 0$, all i.

$-P(i) \cdot y(i) \geq CS_{a(i)}$, $a(i) \geq 0$, $a(i) \cdot (-P(i) \cdot y(i) - CS_{a(i)})$, all i.

These first order conditions are quite informative. First notice that for positive selectivity or discarding to be optimal the net price, $P(i)$, must be negative. Second, the conditions highlight that discarding and selectivity are in a certain sense substitute activities. Both are employed to reduce the landings of unwanted fish, i.e. fish for which the net landing price, $P(i) \equiv p(i)-CL(l(i))- \Omega$, is negative. However, they are not necessarily used to the same extent. If for instance the marginal cost of discarding is less than the marginal cost of selectivity at zero selectivity, i.e.,

$$CD_{d(i)}(d(i)) < CS_{a(i)}(0)$$

then the profit maximizing vessel will only employ discarding to avoid unwanted fish.

Contrariwise, if the marginal cost of discarding at zero discarding is higher than the marginal cost of selectivity. i.e.,

$$CS_{a(i)}(a(i)) < CD_{d(i)}(0)$$

then the profit maximizing vessel will only employ catch selectivity to avoid unwanted fish and not discard at all.

Finally, selectivity and discarding may easily co-exist in the operation of the fishing vessel. The condition for that is simply that

$$CS_{a(i)}(a(i)) = CD_{d(i)}(d(i)).$$

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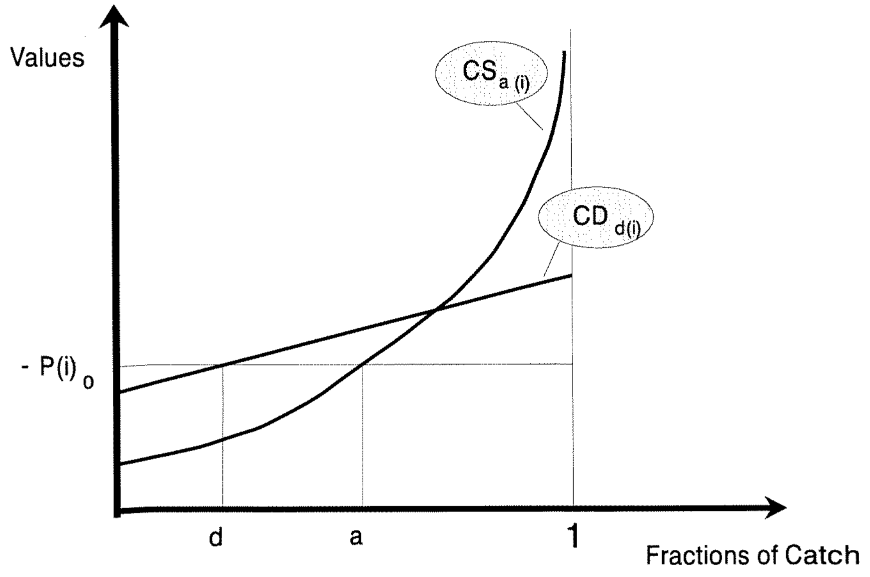
2 By a simple application of the Kuhn-Tucker theorem see e.g. L,onard and Long (1992).

These basic ideas can be usefully depicted diagrammatically as in figure 3.

Figure 3
Optimal discarding and selectivity



In Figure 3 the marginal cost of discarding and selectivity intersect the benefits of not landings (i.e., the negative of the net price[3]) at *d* and *a* respectively. This means that the optimal selectivity will be *a* and a fraction *d* of the harvest (after selectivity) will be discarded. Thus the quantity of discards of fish of grade *i* is $Y(e,x,i)\cdot(1-a)\cdot d$.

The analysis of the effects of an ITQ system on discarding and selectivity is generally quite complicated. In principle it involves studying the response of the complete set of first order conditions to a switch in the opportunity cost of quotas, Ω, from zero to a positive value. The analysis, however, becomes very easy if we make the simplifying assumption that the net landings price per grade of fish, $P(i)$, is exogenous to the vessel.[4] Adopting this assumption we can simply differentiate the appropriate first order conditions to obtain:

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3 Which according to the necessary conditions must be negative for discarding or selectivity to be profitable.

4 This appears very reasonable for the gross landings price and the quota value, p(i) and s, respectively. The assumption that the marginal handling and landing cost is independent of e.g. the volume of harvest appears somewhat more doubtful but not unreasonable.

$\partial d(i)/\partial\Omega = 1/CD_{dd}(i) > 0$, for an interior solution (zero otherwise).

$\partial a(i)/\partial\Omega = y(i)/CS_{aa}(i) > 0$, for an interior solution (zero otherwise).

Realizing that only harvested fish can be discarded it is obvious from the above that a switch to an ITQ system can both increase or decrease the volume of discards. It depends on the situation, especially the shape of the discarding and selectivity cost functions whether selectivity responds sufficiently greatly to an increase in s to overwhelm the impact on discarding. To further examine this, let us represent the quantity of discarding of fish of grade *i* by the expression:

$$D = d \cdot y \cdot (1-a),$$

where D denotes the volume of discards and d now represents the fraction of harvested fish discarded. Taking the harvest before selectivity, i.e. y as constant, this expression implies:

$$\partial D/\partial\Omega = y \cdot [(1-a) \cdot \partial d/\partial\Omega - d \cdot \partial a/\partial\Omega]$$

Hence, for the volume of discards to increase

$$\partial d/\partial\Omega > \partial a/\partial\Omega \cdot d/(1-a).$$

Thus, for instance, if selectivity is already high (little harvest to discard) $\partial d/\partial\Omega$ must be very high relative to $\partial a/\partial\Omega \cdot d$ for the volume of discards to increase.

The issue can perhaps be clarified with the help of a diagram. Referring to the diagram in Figure 3, an increase in Ω means that the net price of landings is reduced. For a grade of fish with an initially negative net price this means a shift of the $-P(i)$ line upward. Hence both the optimal selectivity fraction and the optimal discarding of harvested fish increase as illustrated in Figure 4.

Figure 4
Effects of an increase in Ω on discarding and selectivity

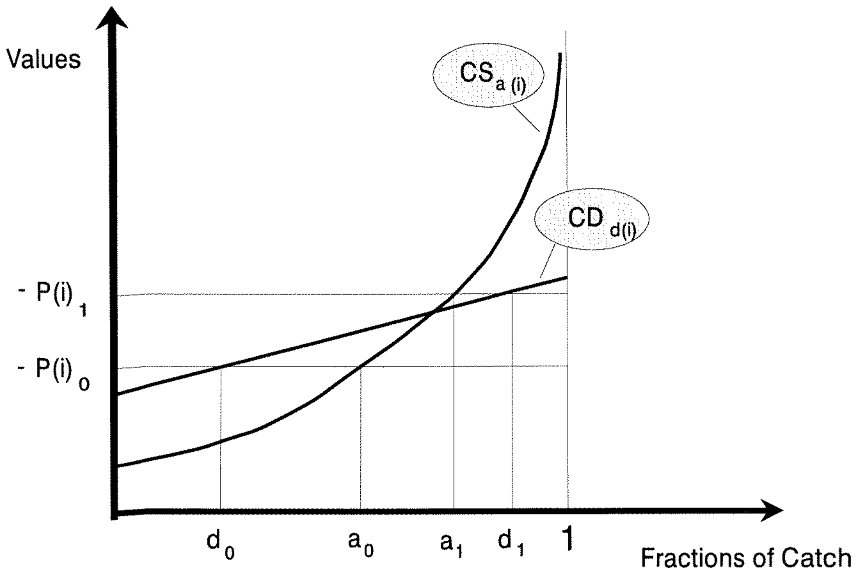

Figure 4 suggests that whether or not discarding increases as a consequence of an ITQ system depends very much on the shape of the discarding and selectivity cost functions. To verify this consider for instance the following example:

Let there be a switch in quota prices from Ω_0 to Ω_1, where $\Omega_1 > \Omega_0$. Let the initial discard and selectivity fractions, d_0 and a_0, be 0.4 and 0.5 respectively. Similarly let d_1 and a_1 be 0.6 and 0.7 respectively which is entirely possible. Then $D_0 = 0.2 \cdot y$ and $D_1 = 0.18 \cdot y$, so the volume of discards actually decreases. This shows that the volume of discards under an ITQ system may actually decrease compared to the volume of discards in an unmanaged fishery.

References

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