Marine Resource Economics, Volume 11, pp. 59–69

0738-1360/96 $3.00 + .00

Value-based ITQ's

MATTHEW A. TURNER
University of Toronto

Abstract *There is empirical and theoretical evidence indicating that quota-induced highgrading is a problem in weight-based ITQ programs. This paper examines value-based ITQ programs as a possible solution to this problem. It is shown that value-based ITQ programs do not provide an incentive to highgrade, and may achieve a target harvest with greater accuracy than weight-based ITQ programs. Two ways of administering value-based ITQ programs are suggested. Though both are arguably more difficult to administer than a weight-based ITQ program, a value-based ITQ program may be less complicated than a weight-based ITQ program coupled with the sorts of taxes, landings restrictions, or multiple quotas, that have been proposed as remedies for quota-induced highgrading.*

Keywords Fisheries regulation, tradable quota, value-based quota.

Introduction

In an Individual Transferable Quota (ITQ) program, a planner limits fishery production by issuing quotas for particular amounts of fish. While there are many ways of issuing quotas and administering ITQ programs, two characteristics are definitional: (1) a fisher may only (legally) bring fish to market if he acquires quotas for at least that weight of fish, and (2) quotas are transferable. In almost all existing programs, quotas entitle a holder to land a particular weight of fish. These "weight-based" ITQ programs are shown to cause discarding in Anderson (1994) and Arnason (1994). This paper investigates the possibility of reducing discarding by using quotas which entitle the holder to land a particular value of fish, rather than a particular weight. It is shown that such "value-based" ITQ programs never provide the incentive to discard that may exist under a weight-based ITQ program. It is also shown that value-based ITQ's can allow a planner to achieve target harvests with greater accuracy than weight-based ITQ's.

Because shipboard monitoring is costly, ITQ programs typically regulate the amount of fish that is landed and brought to market, rather than the amount that is harvested. This means that a manager does not observe any discarding that occurs before landing. Since a weight-based ITQ program obligates the fisher to purchase costly quota for each pound of fish landed, these programs may create an incentive for fishers to discard less valuable fish in order to reduce their quota purchases. This practice will be referred to as "quota-induced highgrading," a terminology that distinguishes between highgrading undertaken to avoid buying quota, and "technologically-induced highgrading" that occurs because the hold is full or because the price of fish does not cover processing costs.

Matthew A. Turner is assistant professor in the Department of Economics, University of Toronto, 150 St. George Street, Toronto, Canada M5S 3G7; e-mail: mturner@epas.utoronto.ca
I am grateful to Steve Edwards, Porter Hoagland, Steve Kohlhagen, Virginia Brett, Martin Boileau, and two anonymous referees for their comments and assistance. Remaining errors are my own responsibility. I am also grateful for the support of the Woods Hole Oceanographic Institution during part of the time this research was conducted.

The distinction between technologically and quota-induced discarding is an important one. Both Anderson (1994) and Arnason (1994) argue that technologically-induced highgrading may maximize social wealth, while quota-induced discarding involves the following social costs: (1) the market value of the discarded fish is lost; (2) because the discarded fish die, the "shadow price," or social value of the fish is lost; (3) the average cost of fishing is increased because all else equal, average cost would be lower if discarded fish were landed; and (4) finally, unobserved discarding may cause the planner to be uncertain about harvest size and this uncertainty may lead to management errors.

There is both theoretical and empirical evidence that quota-induced highgrading occurs. Anderson (1994) and Arnason (1994) both conduct theoretical investigations and find that ITQ programs may induce highgrading. Muse and Schelle (1989) provide a detailed description of twelve individual quota programs. Of these twelve, highgrading is known or suspected in at least four. In one program, a Wisconsin trout fishery (p. 63), highgrading increased when planners switched from quotas based on weight of fish to quotas based on numbers of fish. This suggests that the quota program was at least partly responsible for the highgrading problem. This appears to be the case in the other programs as well, though there is slightly more room to suspect that highgrading is technologically-induced.

In short, there is reason to believe that quota-induced highgrading occurs and that this highgrading is undesirable. This paper argues that value-based ITQ programs cannot induce discarding, and may allow a planner to achieve target harvests with greater accuracy than is possible with weight-based ITQ programs.

The Fishery and Its Response to Weight-based ITQ's

Consider a stock of fish that consists of fish of type 1 and type 2. Although the analysis applies whenever two types of fish with different prices are covered by the same quotas, I have in mind that type 1 and type 2 are smaller and larger members of the same species. Since the analysis describes behavior over a relatively short period of time, the number of fishers is assumed constant at N and is indexed by j. Similarly, the level of the fish stock is taken as fixed over the time period in question.

Let h_{j1} (h_{j2}) denote the weight of type 1 (type 2) fish harvested by fisher j. Each fisher takes market prices as given and the N fishers together are assumed "small enough" that they face perfectly elastic demand. Let p_1 and p_2 denote the market prices of one pound of each type of fish, with $p_2 > p_1 > 0$. Each fisher chooses to apply effort E_j to the fishery at a cost $C_j(E_j)$. Assume that $C_j(0) = 0$, $C_j' > 0$, $C_j'' > 0$. Because the level of the fish stock is fixed, it is omitted from the model. Each fisher also chooses a quantity, D_j, of type 1 fish to discard. Discarding involves a cost of C_{D_j} per pound. Harvest of type 1 (type 2) is related to effort according to $h_{j1} = \alpha_{j1}E_j$, ($h_{j2} = \alpha_{j2}E_j$) where α_{j1} and α_{j2} describe the "catchability" of each type for fisher j. The catchability parameters also determine the composition of each fisher's harvest. The model is imagined to describe behavior over the course of a season or a year, so that hold constraints are implicit in the function C. This is analytically convenient, and allows the analysis to focus on the seasonal aggregates in which the planner is most likely to be interested.

Given the model above, but dropping the j subscript for legibility, a small profit maximizing fisher chooses D and E to solve

$$\max_{D,E} \; (\alpha_1 p_1 + \alpha_2 p_2)E - C(E) - (p_1 + C_D)D$$
$$\text{s.t.} \quad D \geq 0$$
$$D - \alpha_1 E \leq 0.$$

The first term in the fisher's objective function is the total revenue generated by effort E. The second term is the cost of this effort and the third is the cost of discarding D pounds of type 1 fish.

As noted by Anderson (1994), the postulated production technology does not allow fishers any control over the composition of their catches. It also implicitly requires separability in inputs and outputs. While these objections may preclude using the model as the basis for estimation, the simplicity of the fixed proportions technology, and its ubiquity in the fisheries economics literature, make it suitable for the examination of different regulatory policies.

Anderson (1994) examines the impact of a hold constraint on discarding behavior and argues that discarding decisions are made on a trip by trip basis. To adjust the current framework so that it reflects trip level behavior, suppose that a vessel's hold may contain no more than B pounds of fish. In this case, a "hold constraint" may be written $B \geq (\alpha_1 + \alpha_2)E - D$. It is straightforward to incorporate this constraint into the analysis that follows. This is not done because, in the presence of a hold constraint, fishers may highgrade for a technological reason—the hold is full. Neglecting the hold constraint allows the analysis to concentrate exclusively on its chosen topic—quota-induced highgrading.

Suppose a fishery like the one described above is regulated by a planner who has put in place a weight-based ITQ program. In this case, a planner restricts harvest by issuing W units of quota and requiring that each fisher hold one unit of quota for each pound of fish he brings to market. Fishers are permitted to buy or sell quota at a market price p_w.

Under a weight-based ITQ program, a small profit maximizing fisher chooses D and E to solve

$$\max_{D,E} \; (\alpha_1 p_1 + \alpha_2 p_2)E - C(E) - (p_1 + C_D)D - p_w[(\alpha_1 + \alpha_2)E - D]$$
$$\text{s.t.} \quad D \geq 0$$
$$D - \alpha_1 E \leq 0.$$

This maximization is identical to the one solved in the absence of regulation, save that the fisher must purchase quota for each pound of fish landed. Quota purchases are described by the fourth term in the fisher's objective function.

Figure 1 illustrates the solution to this profit maximization problem in the case when $C_D = 0$. The figure illustrates isoquants of a fisher's revenue function, $R_w(h_1, h_2) = (p_1 - p_w)h_1 + (p_2 - p_w)h_2$, and also iso-cost lines, *i.e.*, loci such that $C[\max(\frac{h_1}{\alpha_1}, \frac{h_2}{\alpha_2})]$ is constant. Figure 1a illustrates the case when $p_1 - p_w > 0$ and no discarding occurs. Figure 1b illustrates the case when $p_1 - p_w < 0$ and discarding is profit maximizing. In short, figure 1 shows that if the price of quota is too high, a fisher maximizes profits by highgrading, and discarding type 1 fish. This same result has been obtained by Arnason (1994), and Anderson (1994) in slightly more general frameworks, and is worked out more rigorously in Turner(1995b).

Value-based ITQ's

Several solutions to the problem of quota induced highgrading have been proposed. Arnason (1994) observes that "highgrading" may be regarded as an enforcement problem, and solved by adjusting penalties and monitoring effort appropriately. Anderson (1994) considers the possibility of landings taxes, or sanctions on landings, that are thought to involve quota-induced discarding. The prospect of issuing separate quota for each type is also considered. This section proposes a different solution. It argues that issuing value-based quota rather than weight-based quota will remove the incentive to highgrade.

Consider a fishery like the one considered in the last section, but suppose that a planner regulates the fishery with a value-based ITQ program. Such a quota program operates in much the same way as a weight-based ITQ program, except that the fisher is required to hold a unit of quota for each dollar of fish he brings to market, rather than for each pound. The manager restricts the value of the fish brought to market to V dollars, by distributing quota for that value of harvest. As with a weight-based program, the fisher is able to buy or sell value-based quota at a market price. Let p_v denote the market price of quota entitling the holder to bring to market one dollar's worth of fish.

Under a value-based quota program, a small profit maximizing fisher chooses E and D to solve

$$\max_{D,E} \; (\alpha_1 p_1 + \alpha_2 p_2)E - C(E) - (p_1 + C_D)D - p_v[(\alpha_1 p_1 + \alpha_2 p_2)E - p_1 D]$$
$$\text{s.t.} \quad D \geq 0$$
$$D - \alpha_1 E \leq 0.$$

A fisher's objective function under value-based quota is identical to a fisher's objective under weight-based quota, except that the fourth term of this function reflects the fact that quota is purchased for each dollar of fish landed, rather than each pound.

To see that highgrading cannot be profit maximizing, consider the Lagrangian for the maximization problem above

$$\mathcal{L} = (1 - p_v)(\alpha_1 p_1 + \alpha_2 p_2)E - C(E) - [(1 - p_v)p_1 + C_D]D + \phi(D - \alpha_1 E). \qquad (1)$$

Ignoring the case where $E = 0$ (and no highgrading occurs), the necessary conditions for a maximum are

$$\mathcal{L}_E = (1 - p_v)(\alpha_1 p_1 + \alpha_2 p_2) - C'(E) - \phi\alpha_1 = 0 \qquad (2)$$

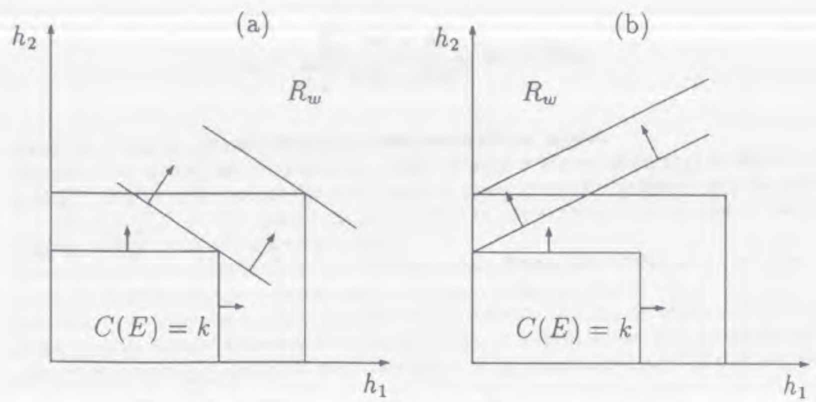

Figure 1. Profit Maximization With Weight-Based ITQ's

$$\mathcal{L}_D = -(1 - p_v)p_1 - C_D + \phi \; \begin{matrix} \geq \\ = \\ \leq \end{matrix} \; 0 \text{ as } \begin{cases} D = \alpha_1 E \\ D \in (0, \alpha_1 E) \\ D = 0 \end{cases} \qquad (3)$$

$$\mathcal{L}_\phi = D - \alpha_1 E \leq 0, \; \phi \geq 0, \; \phi(D - \alpha_1 E) = 0. \qquad (4)$$

From (4), $\phi \geq 0$. If $E > 0$, then $\phi \geq 0$ together with (2) requires that $(1 - p_v) > 0$. Profits associated with a particular choice of D are

$$\Pi = (1 - p_v)(\alpha_1 p_1 + \alpha_2 p_2)E - C(E) - [(1 - p_v)p_1 + C_D]D.$$

Since $(1 - p_v) > 0$ it follows that $D > 0$ is never profit maximizing.

Because value-based quotas decrease the revenue associated with type 1 fish by a fraction less than one, the benefit from discarding a unit of type 1 fish can never equal its market price.[2] More generally, weight-based ITQ programs distort the relative fish prices faced by the fisher, while value-based quota programs do not. Since the capacity to distort relative prices is intrinsic to the quota programs, and not the production technology, it seems likely that weight-based ITQ programs will distort fishing behavior and value-based quotas will not for a larger class of production technologies than is examined here. This is born out in Turner (1995a).

Figure 2 provides a graphical solution to a fisher's maximization problem under a value-based quota program when discarding is costless. The figure illustrates isoquants of the revenue function, $R_v(h_1, h_2) = (p_1 h_1 + p_2 h_2)(1 - p_v)$, and iso-cost lines identical to those in figure 1. Since the slope of the revenue isoquants is always positive for positive fish prices, the negative slope necessary to make highgrading profitable can never occur. This is different from weight-based ITQ programs where the slope of the revenue function can be negative for some combinations of fish and quota prices.

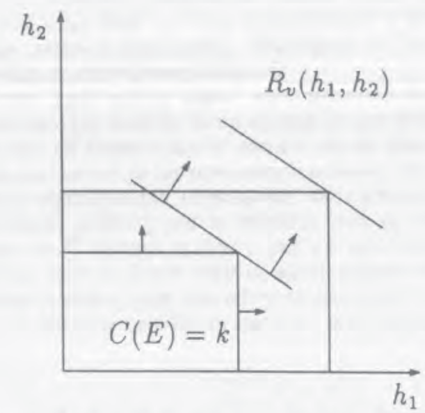

Figure 2. Profit Maximization With Value-Based ITQ's

[2] I am grateful to a referee of this journal for suggesting this intuition.

Fishery Management with Value-Based ITQ's

The value-based ITQ program analyzed above is of interest because, unlike weight-based ITQ programs, it cannot provide an incentive to highgrade. On the other hand, this type of program is problematic because it requires that the manager regulate the value of fish brought to market, when it is the weight of harvested fish that is relevant to fisheries management. This section investigates the possibility of regulating harvest weight with value-based ITQ's.

Let $H = \sum_{j=1}^{N} h_{j1} + h_{j2}$ denote the total weight of fish landed by the N fishers, and let $V = \sum_{j=1}^{N} p_1 h_{j1} + p_2 h_{j2}$ denote the total value of these landings. Suppose that the planner wants to restrict the harvest to H^* pounds with a value-based ITQ program. To do so, he issues V^* dollars worth of value-based quota, where

$$V^* = \frac{\sum_{j=1}^{N} p_1 h_{j1} + p_2 h_{j2}}{\sum_{j=1}^{N} h_{j1} + h_{j2}} H^* = \bar{p} H^*.$$

If the quota is binding, then the fishery will land H^* pounds of fish. Moreover, since there is no incentive to highgrade, total harvests and total landings coincide, and the planner achieves the desired target harvest.

However, the planner must choose and issue quota before the season starts and prices are observed, so that the planner chooses V while still uncertain about the eventual value of $\bar{p}$. While we might expect the planner to make good predictions of $\bar{p}$, we should not expect these predictions to be perfect. Hence we should not expect that a fishery managed with value-based quotas will ever harvest exactly the target amount H^*.

While this observation is disturbing, it need not provide a basis for preferring weight-based ITQ programs to their value-based counterparts. To see this note that if highgrading occurs in a weight-based ITQ program, then the quantity of discarding is not observed by the planner. In theory, if the planner knew (with certainty) all of the parameter values for the fishery before issuing weight-based quota, then the planner could calculate the amount of discarding that would occur and compensate by decreasing the amount of quota. In practice, the planner will always be uncertain about the various parameter values. Hence, in the presence of highgrading, we should not expect that a fishery managed with weight-based quotas will ever harvest exactly the target amount H^*. The next section will discuss this problem at greater length and develop a method for comparing the accuracy with which the two types of quota program achieve a particular target harvest.

While it does not appear to be possible to eliminate all uncertainty from the relationship between V^* and H^*, a slightly different way of administering value-based quota can remove uncertainty due to shifts in the price level. To see this, let $(p_1, p_2) = (\gamma p_1', \gamma p_2')$ where (p_1', p_2') are deterministic relative prices, and γ is a random price level that is not observed until the start of the fishing season. If the value-based-quota is binding then

$$\sum_{j=1}^{N} p_1 h_{j1} + p_2 h_{j2} = V^*.$$

Dividing by p_2 gives

$$\sum_{j=1}^{N} \frac{p_1}{p_2} h_{j1} + h_{j2} = R^*,$$

where

$$R^* = \frac{V^*}{p_2} = \frac{\sum_{j=1}^{N} p_1 h_{j1} + p_2 h_{j2}}{p_2\left(\sum_{j=1}^{N} h_{j1} + h_{j2}\right)} H^*. \tag{5}$$

This expression is invariant to changes in the price level. Moreover, since R^* is denominated in pounds of type 2 fish, this equation describes an ITQ program where the planner issues R^* units of quota, each of which entitles the holder to land one pound of type 2 fish, or $\frac{p_2}{p_1}$ pounds of type 1 fish, *i.e.* each unit of quota entitles the holder to land one pound of type 2 fish, or an equal value of type one fish.

This approach to administering value-based quota has at least two advantages. First, it reduces the uncertainty in the relationship between harvest value and harvest weight by relying only on relative prices, and not on the price level. Second, it resembles a weight-based ITQ program more closely in that quota continues to be denominated in pounds. This should reduce administrative difficulties involved in switching from weight to value-based regulation.

To see that this "relative-value-based" quota does not provide an incentive for discarding, let p_r denote the price of a unit of such quota. A small profit maximizing fisher subject to a relative-value-based quota chooses D and E to solve

$$\max_{D,E} \; (\alpha_1 p_1 + \alpha_2 p_2)E - C(E) - (p_1 + C_D)D - p_r\left[\left(\alpha_1 \frac{p_1}{p_2} + \alpha_2\right)E - \frac{p_1}{p_2} D\right]$$

$$\text{s.t.} \quad D \geq 0, \quad D \leq \alpha_1 E.$$

To see that discarding cannot be profit maximizing, first form the Lagrangian for a fisher's maximization problem

$$\mathcal{L} = \left(1 - \frac{p_r}{p_2}\right)(\alpha_1 p_1 + \alpha_2 p_2)E - C(E) - \left[\left(1 - \frac{p_r}{p_2}\right)\right]p_1 + C_D)D + \phi(D - \alpha_1 E).$$

This Lagrangian is identical to the one associated with value-based quota programs, with p_r/p_v in place of p_v. This reflects the fact that value-based and relative value-based quotas are identical except that a unit of the former allows one dollar of harvest, while a unit of the latter allows p_2 dollars of harvest. Consequently, the proof that relative-valued-quota does not induce discarding is identical to that presented earlier for value-based quota.

It is interesting to note that the one real world example of a value-based ITQ program (of which I am aware) is administered in much the same way as is described above. Muse and Schelle (1989, p. 54) describe an Icelandic fishery in which,

> ... operators are allowed to trade quota in one species for quota in another with the fisheries ministry. They may convert 5% of their quota in any other species to Cod, and make unlimited trades of Cod to other species. These trade-off ratios, based on relative fish prices, are published in regulations... .

Although this passage describes a multi-species fishery, if we substitute "type 2" for "Cod" and "type 1" for "other species," and suppose that only quotas for type 2/cod are issued, then the Icelandic program corresponds exactly to the value-based ITQ program described by equation (5). While Muse and Schelle do not provide enough information to allow an assessment of whether or not this program reduces discarding relative to a weight-based program, the existence of the program demonstrates that value-based programs are feasible.

Finally, it may be the case that buyers and sellers are able to collude to record prices below the market price, with the difference made up by "black market" payments unobserved by the regulator. However, the same objection may be made to weight-based ITQ's. Buyer and seller may collude so that pounds of fish change hands on the black market, without the planner's knowledge. While it may be difficult to prevent fishermen from misrepresenting prices, it is probably no more difficult than preventing them from misrepresenting landed weight. Moreover, the planner should be able to substantially overcome this problem by using an average market price to assess how much quota is required for a particular transaction, rather than the price at which the transaction actually took place.

Accuracy of Different Quota Types

Two criteria which planners might use to choose a type of quota program are (1) quantity of discarding induced, and (2) accuracy with which a target harvest is obtained. Thus far, this paper has primarily discussed quota-induced discarding. This section assesses the relative accuracy of the weight and relative value-based ITQ programs, given the planner's information about relative prices and the ratio of the catchability parameters.

To simplify the exposition, assume that all fishers are identical, and omit the j subscript. From section 2, the harvest of types 1 and 2 is given by $h_1 = \alpha_1 E$, and $h_2 = \alpha_2 E$. Without loss of generality, renormalize units of effort so that $h_1 = E$, and $h_2 = \alpha E$, where $\alpha = \alpha_1/\alpha_2$. Further suppose that costs are sufficiently low that a relative value-based quota will be binding, and that a weight-based quota will be binding and induce the maximum discarding of type 1 fish (*i.e.* the whole catch, $D = \alpha E$).

Under these conditions, if the planner issues W units of weight-based quota then the fishery lands W pounds of the more valuable type 2 fish, and discards $\frac{1}{\alpha} W$ pounds of type 1 fish. The total harvest is $H = (1 + \frac{1}{\alpha})W$ pounds. If the planner knows α with certainty, he can achieve a target harvest H^* by choosing $W^* = H^*/(1 + \frac{1}{\alpha})$. If the planner is uncertain about α, then we can regard α as a random variable whose variance, σ_α^2, is a measure of the planner's uncertainty about the ratio of types that will be harvested over the period of time when the quota program is in effect. In this case, the planner can achieve a target harvest H^* in expectation by issuing the amount of weight based quota $W(H^*)$ that satisfies $H^* = W(H^*)E(1 - \frac{1}{\alpha})$. Rearranging gives $W(H^*) = H^*/E(1 + \frac{1}{\alpha})$. By construction, if the planner issues this amount of weight-based quota then,.on average, the target harvest is obtained. Note that $\alpha = h_1/h_2$, so that $W(H^*)$ or any other function of α can be estimated from a sample of harvests for which no quota-induced discarding occurs.

Since the variance of the harvest under this policy is a measure of the accuracy with which weight-based quota programs hit their targets, harvest variance under this policy is of interest. The variance of harvest weight, conditional on issuing the $W(H^*)$ units of weight-based quota is

$$\mathrm{var}[H|W(H^*)] = H^{*2}\left[\frac{E(1+\frac{1}{\alpha})^2}{\left[E(1+\frac{1}{\alpha})\right]^2} - 1\right]. \quad (6)$$

This expression is a measure of the accuracy with which weight-based quota programs achieve target harvests in a fishery where discarding occurs, and it may be easily estimated from a set of realizations of α.[3]

One may also analyze the accuracy of relative value-based quota. Assuming identical fishers and rearranging equation (5) shows that the relationship between harvest weight and relative value-based quota is $H = \frac{\alpha+1}{p\alpha+1}R$. In the absence of uncertainty, the planner obtains a target harvest of weight H^* by issuing $R^* = \frac{p\alpha+1}{\alpha+1}H^*$ units of relative value-based quota. If the planner is uncertain about α and p, then H^* can be achieved in expectation by choosing $R(H^*) = H^*/E(\frac{\alpha+1}{p\alpha+1})$. Harvest variance, conditional on issuing $R(H^*)$ units of relative value-based quota is

$$\mathrm{var}[H|R(H^*)] = H^{*2}\left[\frac{E\left(\frac{\alpha+1}{p\alpha+1}\right)^2}{\left[E\left(\frac{\alpha+1}{p\alpha+1}\right)\right]^2} - 1\right]. \quad (7)$$

As with weight-based quota, harvest variance under relative value-based quota provides a measure of the accuracy with which this type of ITQ program achieves a target harvest. If p and α are jointly observed, then $\mathrm{var}[H|R(H^*)]$ can be estimated from this set of observations. Alternately, if p and α are not jointly observed, then densities for p and α may be estimated and $\mathrm{var}[H|R(H^*)]$ evaluated on the basis of estimated densities.

Taken together, expressions (6) and (7) provide the planner with a very tractable way to compare the accuracy of weight-based quota with the accuracy of relative value-based quota. The planner need only evaluate the two expressions and compare their magnitudes. A few comments about this procedure are in order. First, because the computation of $\mathrm{var}[H|W(H^*)]$ assumes that all type 1 fish are discarded, (6) is in fact an upper bound on harvest variance of weight-based quota programs. This means that (6) is only a useful measure of regulatory accuracy in fisheries where quota-induced discarding is a severe problem. This criticism does not apply to $\mathrm{var}[H|R(H^*)]$. Second, the calculations of both $\mathrm{var}[H|W(H^*)]$ and $\mathrm{var}[H|R(H^*)]$ are based on the rather restrictive assumptions made earlier in the paper. Two in particular, the assumption that fishers cannot control their catch composition, and that demand is perfectly elastic, are probably counter-factual. In reality, p and α may be expected to have non-zero covariance, and the assumptions prohibiting control over catch composition and requiring perfect price elasticity preclude this possibility. Thus the estimate of $\mathrm{var}[H|R(H^*)]$ is imperfect. Constructing a measure of regulatory accuracy based on weaker assumptions is a subject for further research.

In order to develop some intuition about the conditions under which relative value-based quota is more accurate than weight-based quota, suppose that p and α are random variables with the following distributions

$$p = \begin{cases} \bar{p} + \sigma_p & \text{with probability } \frac{1}{2} \\ \bar{p} - \sigma_p & \text{with probability } \frac{1}{2} \end{cases}$$

$$\alpha = \begin{cases} \bar{\alpha} + \sigma_\alpha & \text{with probability } \frac{1}{2} \\ \bar{\alpha} - \sigma_\alpha & \text{with probability } \frac{1}{2} \end{cases}$$

[3] Note that while $W(H^*)$ may also be easily calculated from a set of observations of α, it is not generally true that $W(H^*) = H^{*2}/[1 - 1/E(\alpha)]$.

In this case, changes in σ_p and σ_α represent mean preserving changes in variance (increases or decreases in the quality of the planner's information about p and α), while changes in $\bar{p}$ and $\bar{\alpha}$ represent variance preserving shifts in parameter means. To see where relative value-based quota is more accurate than weight-based quota, figure 3 plots

$$\Delta V = \frac{\text{var}[H|R(H^*)] - \text{var}[H|W(H^*)]}{H^{*2}}$$

as σ_α^2 and σ_p^2 vary, holding $\bar{p}$ and $\bar{\alpha}$ constant at one half. Since ΔV is just the normalized difference between harvest variances under the two types of ITQ program, when ΔV is negative, weight-based quota is less accurate than value-based quota.

The dashed line in figure 3 indicates the zero isoquant. Unsurprisingly, when σ_p^2 is large and σ_α^2 is small, ΔV is positive. That is, when the planner has bad information about prices, and good information about the technology, then value-based quota is less accurate than weight-based quota. In all other cases, value-based quota programs are more accurate than weight-based ITQ programs. Replotting figure 3 (not shown) with different values for $\bar{p}$ and $\bar{\alpha}$ makes almost no difference to the appearance of the figure. Although results based on figure 3 and related plots should clearly be regarded as preliminary, this figure is a little startling. Despite the fact that value-based ITQ programs introduce price-based uncertainty into the problem, and weight-based ITQ programs do not, figure 3 indicates that in most information states value-based quota is more accurate than weight-based quota. Generalizing and refining this intuition is a subject for further research.

Conclusion

There is empirical and theoretical evidence indicating that quota-induced highgrading is a problem in weight-based ITQ programs. This paper examines value-based ITQ programs as a possible solution to this problem and finds that value-based ITQ programs do not provide an incentive to highgrade.

Two ways of administering value-based ITQ programs are suggested. In the first, the planner issues dollar denominated quota, each unit of which entitles its holder to land one dollar's worth of fish regardless of type. In the second, the planner issues weight denominated quota, each unit of which entitles its holder to bring to market one pound of type 2 fish, or an equal value of type 1 fish. Both ways of administering value-based ITQ programs are imperfect in that they do not allow the planner to know for certain the relationship between quota issued and fish harvested. The second way of administering value-based ITQ programs reduces this uncertainty by relying only on relative prices, and not on the nominal price level. Because the relationship between quota issued and fish harvested is also uncertain in weight-based ITQ programs, this problem need not constitute a reason to prefer weight-based to value-based programs. In fact, an analysis of the accuracy of relative value-based and weight-based ITQ programs suggests that, except when information about prices is poor, and information about catch ratios is good, value-based ITQ programs achieve a target harvest with more accuracy than their weight-based counterparts.

Finally, both ways of administering value-based ITQ programs are arguably more difficult to administer than a weight-based ITQ program. However, as the Icelandic program shows, these difficulties are surmountable and a value-based ITQ program is feasible. Moreover, a value-based ITQ program may be less complicated than a weight-based ITQ program coupled with the sorts of taxes, landings restrictions, or multiple quotas, that are proposed as remedies for highgrading in Arnason (1994) and Anderson (1994).

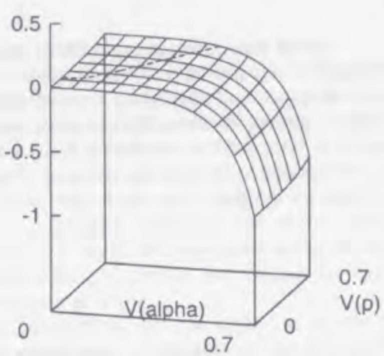

Figure 3. Normalized Difference Between Harvest Variances of Value and Weight-Based ITQ's

References

Anderson, L.G. 1994. An Economic Analysis of Highgrading in ITQ Fisheries Regulation Programs. *Marine Resource Economics* 9(3):209–26.

Arnason, R. 1994. On Catch Discarding in Fisheries. *Marine Resource Economics* 9(3):189–207.

Copes, P. 1989. A Critical Review of the Individually Transferable Quota as a Device in Fisheries Management. *Land Economics* 62(3):278–91.

Muse, B. 1991. *Survey of Individual Quotas Programs.* Juneau, Alaska: Alaska Commercial Fisheries Entry Commission.

Muse, B., and K. Schelle. 1989. *Individual Fisherman's Quotas: A Preliminary Review of Some Recent Programs.* Juneau, Alaska: Alaska Commercial Fisheries Entry Commission.

Turner, M. 1995a. Quota-induced Discarding in a Heterogenous Fishery. University of Toronto working paper, UT-ECIPA-MTURNER-95-02.

——. 1995b. Value-based ITQ's. University of Toronto working paper, UT-ECIPA-MTURNER-95-03.