Department of Economics
and
Institute for Policy Analysis
University of Toronto
150 St. George Street
Toronto, Ontario M5S 1A1
Canada

December 12, 1995

WORKING PAPER

NUMBER UT-ECIPA-MTURNER-95-03

Value-based ITQ's

Matthew A. Turner

ISSN 0829-4909

Author's email: mturner@epas.utoronto.ca
Online version:/ecipa/wpa.html

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. 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 are proposed as remedies for quota-induced highgrading in Arnason (1994) and Anderson (1994). JEL Classifications: Q22, K32.

1. Introduction

In an Individual Transferable Quota (ITQ) program, a planner limits fishery production by issuing quotas for particular amounts of fish. [1] While there are many ways of issuing quotas and administering ITQ programs, two characteristics are definitional. A fisher may only (legally) bring fish to market if he acquires quotas for at least that weight of fish, and 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.

Since shipboard monitoring is very expensive, ITQ programs do not typically regulate the amount of fish that is harvested, but rather the amount of fish that is landed and brought to market. Hence, if a fisher discards fish before landing a manager cannot observe the amount. Since a weight-based ITQ program obligates the fisher to purchase costly quota for each pound of fish landed, in a fishery where different sizes of fish sell for different prices, an ITQ program 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 is not related to the quota program. This distinction is important since both Anderson (1994) and Arnason (1994) argue that technologically-induced highgrading may maximize social wealth, while quota-induced discarding does not. In particular, quota-induced highgrading involves the following social costs. The market value of the discarded fish is lost. Since the discarded fish die, the "shadow price", or social value of the fish is lost. Finally the average cost of fishing is increased since, all else equal, average cost would be lower if discarded fish were landed.

Anderson (1994) and Arnason (1994) both conduct theoretical investigations of highgrading and find that ITQ programs may induce highgrading. In addition, 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, a Wisconsin trout fishery(p63), highgrading increased when planners switched from quotas based on numbers of fish to quotas based on weight of fish. This suggests that the quota program was atleast 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 theoretical and empirical evidence that quota-induced highgrading is a problem in ITQ programs.

---

[1] I am grateful to Steve Edwards, Porter Hoagland, Steve Kohlhagen, Virginia Brett, and two anonymous referees for helpful comments on an earlier draft. Remaining errors are my own responsibility. This research was partly supported by the Woods Hole Oceanographic Institution. W.H.O.I. Contribution # 8874.

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

The object of ITQ programs is to reduce fishery harvests over a particular time period. If this time period is sufficiently short, then the stock level of fish may be taken as fixed over the period in question. If we further assume that the fishery in question consists of many small fishers, none of whom is large enough to affect prices in input, fish or quota markets, then it is reasonable to assume that each fisher acts to maximize profits, taking prices as given. The remainder of this section constructs a mathematical model of such a fishery, and shows that a weight-based ITQ program may induce such small, profit maximizing fishers to highgrade.

Consider a stock of fish that consists of two types of fish, indexed by $i \in \{1, 2\}$. Although the analysis applies whenever two types of fish with different prices are covered by the same quotas,[2] I have in mind that type 1 and type 2 are smaller and larger members of the same species. The fish are harvested by N fishers, indexed by j. The number of fishers is taken as fixed and exogenous. While this is a strong assumption, since the analysis is interested in describing behaviour over a relatively short period of time, it is nevertheless reasonable. Moreover, since fishers are not identical, we can regard N as the pool of possible fishers, each of whom chooses to "enter" or "exit" according to whether they are active in a particular season.

For $i \in \{1, 2\}$ let h_{ji} denote the weight of type i fish harvested by fisher j. Each fisher takes market prices as given, and to simplify the analysis, the N fishers together are assumed "small enough" that they face perfectly elastic demand. Let $p_i > 0$ denote the market price of one pound of type i fish. Without loss of generality assume that $p_1 > p_2$. Each fisher chooses to apply effort E_j to the fishery at a cost $C_j(E_j)$. Assume that $C_j(0) = 0,\ C_j' > 0,\ C_j'' > 0$. Since the stock level is assumed fixed over the time period in question it is ommitted from the model. Each fisher also chooses a quantity, D_j, of type 1 fish to discard. Discarding involves a cost of C_{Dj} per pound. Harvest of type i is related to effort according to $h_{ji} = \alpha_{ji} E_j$, where α_{ji} is a parameter describing the "catchability" of fish of type i for fisher j. The model is imagined to describe behaviour over the course of a season or a year so that hold constraints are implicit in the C function. This is analytically convenient, and also 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 choses D and E to solve

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

Several objections to this model are possible. As noted by Anderson (1994), the postulated production technology precludes fishers from exercising any control over the

[2]This occurs on Lake Winnipeg in Manitoba. The total landings of Pickerel, Sauger, and Whitefish are regulated, but there is no quota on the landings of each species. (Muse 1991).

composition of their catch. It also implicitly requires separability in inputs and outputs. Both assumptions are likely to be counterfactual (the first is relaxed in Turner 1995). While these objections 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.

It may also be objected that since discarding decisions are made on a trip by trip basis, the technology should reflect trip by trip rather than aggregate seasonal activity. To accommodate this objection, 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 straight forward to incorporate this constraint into the analysis that follows. This is not 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. In addition, the impact of a hold constraint has been extensively analysed in Anderson (1994). The interested reader is referred to his paper.

Lastly, one may object to the model on the grounds that it allows discarding only of type 1 fish. While this is reasonable, given the assumption that $p_2 > p_1$, the fisher will always discard fish of type one before those of type two, and rather than discard both types a profit maximizing fisher will produce less of both types. Thus precluding discarding of type 2 should be regarded as a simplifying assumption intended to lighten notation.

Having modelled a fishery, it remains to model regulation. The remainder of this section describes a weight-based ITQ program and shows that such a program may induce highgrading. Suppose a fishery is regulated by a planner who has put in place a weight-based ITQ program. Under such a program, 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 such a program, a small profit maximizing fisher chooses D and E to solve

$$\begin{array}{ll} \max\limits_{D,E} & (\alpha_1 p_1 + \alpha_2 p_2)E - C(E) - (p_1 + C_D)D - p_w((\alpha_1 + \alpha_2)E - D) \\ \text{s.t.} & D \geq 0 \\ & D - \alpha_1 E \leq 0. \end{array}$$

To see that discarding may be profit maximizing under such a program, first form the Lagrangian for a fisher's maximization problem,

$$\mathcal{L} = (\alpha_1 p_1 + \alpha_2 p_2)E - C(E) - (p_1 + C_D)D - p_w((\alpha_1 + \alpha_2)E - D) + \phi(D - \alpha_1 E).$$

Ignoring the case where $E = 0$, the Kuhn-Tucker necessary conditions for a maximum are

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

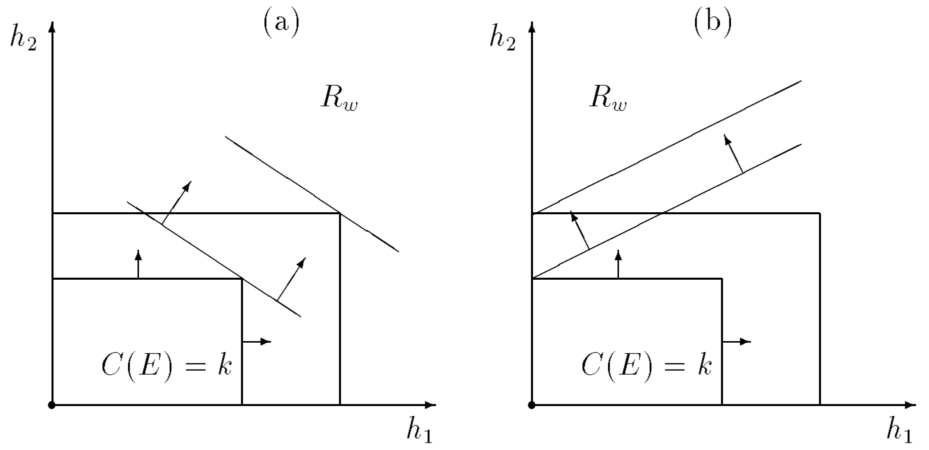
$$\mathcal{L}_D = p_w - (p_1 + C_D) + \phi \begin{array}{c} \geq \\ = 0 \\ \leq \end{array} \text{ as } \begin{cases} D = \alpha_1 E \\ D \in (0, \alpha_1 E) \\ D = 0 \end{cases} \tag{2}$$

$$\mathcal{L}_\phi = D - \alpha_1 E \leq 0, \ \phi \geq 0, \ \phi(D - \alpha_1 E) = 0. \tag{3}$$

To establish conditions under which discarding may be profit maximizing, suppose the converse is true and that profits are maximized when $D = 0$. In this case, from (3), $\phi = 0$. Substituting in (2) gives $p_w - (p_1 + C_D) \leq 0$. Thus if profits are maximized by choosing $D = 0$, then $p_w - (p_1 + C_D) \leq 0$. The contrapositive of this statement gives the desired result: if $p_w - (p_1 + C_D) > 0$ then profits are maximized by choosing $D > 0$. Less formally, if the price of quota is too high, a fisher maximizes profits by discarding type 1 fish. This establishes that weight-based ITQ programs can induce highgrading by profit maximizing fishers. It should be noted that this same result has been obtained by Arnason (1994), and Anderson (1994) in slightly more general frameworks.

Figure 1 illustrates the solution of the above profit maximization problem in the case when $C_D = 0$. The figure illustrates isoquants of a fishers 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 $C(\max(\frac{h_1}{\alpha_1}, \frac{h_2}{\alpha_2}))$ takes a constant value k. 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.

Figure 1.



3. 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 such a 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,

$$\begin{array}{ll} \max\limits_{D,E} & (\alpha_1 p_1 + \alpha_2 p_2)E - C(E) - (p_1 + C_D)D - p_v\left((\alpha_1 p_1 + \alpha_2 p_2)E - p_1 D\right) \\ \text{s.t.} & D \geq 0 \\ & D - \alpha_1 E \leq 0. \end{array}$$

To see that highgrading cannot be profit maximizing, form the Lagrangian for a fisher's maximization problem. After combining like terms this is,

$$\mathcal{L} = (1 - p_v)(\alpha_1 p_1 + \alpha_2 p_2)E - C(E) - ((1 - p_v)p_1 + C_D)D + \phi(D - \alpha_1 E). \tag{4}$$

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

$$\mathcal{L}_E = (1 - p_v)(\alpha_1 p_1 + \alpha_2 p_2) - C'(E) - \phi\alpha_1 = 0 \tag{5}$$

$$\mathcal{L}_D = -(1 - p_v)p_1 - C_D + \phi \begin{array}{c} \geq \\ = 0 \\ \leq \end{array} \text{ as } \begin{cases} D = \alpha_1 E \\ D \in (0, \alpha_1 E) \\ D = 0 \end{cases} \tag{6}$$

$$\mathcal{L}_\phi = D - \alpha_1 E \leq 0, \ \phi \geq 0, \ \phi(D - \alpha_1 E) = 0. \tag{7}$$

From (7), $\phi \geq 0$. If $E > 0$, then $\phi \geq 0$ together with (5) requires that $(1 - p_v) > 0$. The profits associated with a particular choice of D, and $E > 0$ can be written

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

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

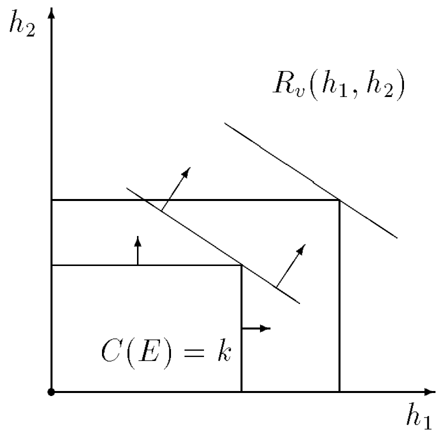
The intuition behind this result is straightforward. Value-based quotas decrease the revenue associated with type 1 fish by a fraction less than one. Hence the benefit from discarding a unit of type 1 fish can never equal its market price. [3] More generally, this conclusion is driven by the fact that 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 behaviour and value-based quotas will not for a larger class of production technologies than is examined here. This is born out in Turner (1995).

Figure 2 provides a graphical solution to a fisher's maximization problem under a value-based quota program when discarding is costless. To show that highgrading cannot occur figure 2 illustrates isoquants of the revenue function, $R_v(h_1, h_2) =$

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

$(p_1 h_1 + p_2 h_2)(1 - p_v)$, 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 in a value-based ITQ program. This is different from weight-based ITQ programs where the slope of the revenue function can be negative for reasonable combinations of fish and quota prices.

Figure 2.



4. Fishery Management With Value-Based ITQ's

The value-based ITQ program analysed 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 $W = \sum_{i=1}^{N} h_{j1} + h_{j2}$ denote the total weight of fish landed by the N fishers, and let $V = \sum_{i1}^{N} p_1 h_{j1} + p_2 h_{j2}$ denote the total value of these landings. Suppose that the planner would like to restrict the harvest to W^* pounds with a value-based ITQ program. If the planner issues V^* dollars worth of value-based quota, where

$$V^* = \frac{\sum_{i=1}^{N} p_1 h_{j1} + p_2 h_{j2}}{\sum_{i=1}^{N} h_{j1} + h_{j2}} W^* = \bar{p} W^*,$$

then the fishery will land W^* pounds of fish. [4] Moreover, since there is no incentive to highgrade, total harvests and total landings coincide, and the planner achieves the desired target harvest.

The problem with this approach is that, while the average price of a pound of fish, $\bar{p}$, is easily observed after the season is over, it cannot be observed before the season starts. Since the planner must choose and issue quota before the season starts, the

[4] This assumes that the quota is binding. The fishery may also land less that W^* pounds.

planner will not observe $\bar{p}$ until it is too late to matter. In theory, if each of the C_j, p_i, and α_{ji} is known, then $\bar{p}$ can be calculated in advance. In practice, this information is unlikely to be available to the planner. The p_i in particular are unlikely to be known until after the fishing season starts.

Although there is a deterministic relationship between the amount of value-based quota issued, and the harvest weight, this relationship cannot be known with certainty by the planner. While we might expect the planner to make "low" variance predictions for the value 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 W^*, though it may often be close.

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 each of the C_j, p_i, and α_{ji}, before issuing weight-based quota, then the planner could calculate the amount of discarding that would occur, and could adjust downward the amount of quota so that the sum of quota and quota-induced discarding equalled the target harvest. In practice, this will not be possible since the p_i are unknown until after the season has begun. While a deterministic relationship exists between the amount of weight-based quota issued and the size of the harvest, this relationship cannot be known to the planner with certainty. While we might expect the planner to make "low" variance predictions of the amount of highgrading, we should not expect these predictions to be perfect. Hence, in the presence of highgrading, we should not expect that a fishery managed with value-based quotas will ever harvest exactly the target amount W^*, though it may often be close. In short, neither weight nor value-based ITQ programs allow the planner perfect control over harvest.

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

$$\sum_{j=1}^{N} \frac{p_1}{p_2} h_{j1} + h_{j2} = R*, \tag{8}$$

where $R^* = \frac{V^*}{p_2} = \frac{\sum_{i=1}^{N} p_1 h_{j1} + p_2 h_{j2}}{p_2 (\sum_{i=1}^{N} h_{j1} + h_{j2})} W^*$. It is easy to see that all terms of this expression are invariant with respect to the price level. Moreover, since R^* is denominated in pounds of type 2 fish, this equation suggests the following simple way of administering a value-based ITQ program. In particular, 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 also 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,

$$\begin{array}{ll} \max\limits_{D,E} & (\alpha_1 p_1 + \alpha_2 p_2)E - C(E) - (p_1 + C_D)D - p_r((\alpha_1 \frac{p_1}{p_2} + \alpha_2)E - \frac{p_1}{p_2}D) \\ \text{s.t.} & D \geq 0 \\ & D \leq \alpha_1 E. \end{array}$$

To see that discarding cannot be profit maximizing, first form the Lagrangian for a fisher's maximization problem. Combining like terms this Lagrangian is,

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

This Lagrangian is identical to the one associated with value-based quota programs, with $\frac{p_r}{p_2}$ 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. Although one might expect that the effects of relative-value-based quota depend on the choice of denominator type, duplicating the analysis outlined above with type 1 as the denominator species shows that this is not the case. This results from the fact that relative value-based quota denominated in units of type 1 fish is identical to value based quota, except that a unit of the former authorizes a harvest of p_1 dollars, while a unit of the latter authorizes a harvest of one dollar.

It is interesting to note that the one real world example of a value-based ITQ program is administered in much the same way as is described above. Muse and Schelle (1989,p54) 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 quota for type 2/cod is issued, then the Icelandic program corresponds exactly to the value-based ITQ program described by equation (8). 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.

Another objection to value-based ITQ programs is also possible. It may also 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 that are beyond the view of the regulator. This is certainly possible. Nevertheless, essentially the same objection may be made against 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.

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. It is shown 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. Since 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.

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).

References

[1] L. G. Anderson, "An Economic Analysis of Highgrading in ITQ Fisheries Regulation Programs," *Marine Resource Economics.* **9** 209-226 (1994).

[2] R. Arnason, "On Catch Discarding in Fisheries," *Marine Resource Economics.* **9** 189-207 (1994).

[3] P. Copes, "A Critical Review of the Individually Transferable Quota as a Device in Fisheries Management," *Land Economics.* **62** 278-291 (1986).

[4] B. Muse and K. Schelle, "Individual Fisherman's Quotas: A Preliminary Review of Some Recent Programs," Alaska Commercial Fisheries Entry Commission (1989)

[5] B. Muse, "Survey of Individual Quotas Programs," Alaska Commercial Fisheries Entry Commission (1991)

[6] M. Turner, "Economics without Free-disposal: Quota-induced Discarding in a Heterogenous Fishery", University of Toronto working paper(1995).