LANDINGS FEES VS. INDIVIDUAL TRANSFERABLE QUOTAS: A DISAGGREGATED ANALYSIS

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ABSTRACT

Weitzman (2002) has shown that with a stochastic growth function and uncertainty in estimating stock size, landing fees will be superior to quotas as a means of controlling fish harvest. Hannesson and Kennedy (2003) expand the analysis by considering variable availability of fish, random fish prices, and non-constant returns to stock in the yield function and show that in some cases quotas will be superior to landings fees. This paper expands the analysis further by using an aggregate analysis where the entry and exit of firms and the necessity of covering fixed costs can be considered. As part of the analysis, the Weitzman conclusions require a TAC time path which uses a most rapid approach to the desired stock size. The paper further extends the Weitzman discussion by introducing a more politically realistic TAC setting program. The extended analysis shows that fees will not always be superior to TAC/ITQs.

Keywords: Landing fee, ITQ, P vs. Q.

INTRODUCTION

Weitzman (2002) shows that with "recurrent ecological uncertainty", "..an optimal landing tax is always superior to an optimal ITQ-style harvest policy." By the latter he means an individual transferable quota scheme which is based on a total allowable catch (TAC) which can vary from year to year. There is no free for all race for the TAC, it is allocated to individual owners and there will be incentives to harvest it as efficiently as possible. Recurrent ecological uncertainty comprises two elements. Both the stock recruitment relationship and the regulator's estimate of beginning stock size is stochastic. In simple terms, the regulator faces a double problem when setting TACs. First, the precise stock size that will result in the next period from a given escapement in the previous period is not known. Second, when making policy there is only an estimate of what the current initial stock size is.

Weitzman's conclusions follow from a standard discrete-time metered aggregate model, an analogous version of which will be presented below. He assumes that regulators try to induce harvest levels which will maximize discounted profits. He then shows that the optimal fisheries policy to do so consists of achieving a particular constant escapement level, and, no matter what the current initial stock size, to obtain that escapement level by the most rapid approach. The logic for concluding that a tax is superior is that " such a constant escapement policy *cannot* be achieved by setting a harvest goal *before* resolving the recruitment uncertainty" but "in contrast, a correctly chosen landing tax can achieve the most rapid approach to *any* escapement level from *any* recruitment level (even when the stock is overfished and optimal policy is to harvest *zero* fish. (P. 336, italics in original.) The reason the optimal landings tax can achieve the most rapid approach is that it is based on the known desired constant escapement level, and not on the unknown but estimated initial stock size as is the harvest goal. A more complete analysis of this conclusion will be provided in the context of the model to be presented below. Weitzman's model is internally consistent and the conclusions are impeccable and not in dispute here. He notes, however, that the results could be different if there is "economic uncertainty" about the profit function.

In a recent paper Hannesson and Kennedy (2003) take a second look at the question taking into economic uncertainty into account. The essence of their argument is that while the optimal landings tax may be a function of the known and constant desired escapement level, it is also a function of price, cost, and the parameters in the production function. These things can vary from season to season and like the initial stock size, their current values may not be known with certainty at the time the optimal tax is set. Therefore while the tax will cause fishing to stop at a particular escapement level, it may be different than the desired level that will lead to the maximization of NPV. Using a Monte Carlo approach, they show that depending on the variability of the economic and technical parameters, the ability to estimate the initial stock size, and upon the relative size of cost and the elasticity of catch with respect to stock size, in some cases ITQ/TAC programs will generate higher profits than will a landing fee. They conclude that fees will not always be superior with respect to maximizing NPV.

The purpose of this paper is to further investigate the relative merits of fees and ITQs and to do so in such a way that more closely depicts real world fisheries management policy. First, the problem will be cast in a disaggregated model which allows for a closer study of how individual operators react to taxes and to the microeconomic operations of an ITQ program when firms have to consider fixed costs. This model raises some important theoretical issues about the use of the two types of regulations even given all of the assumptions of the Weitzman and the Hannesson/Kennedy papers.

The other difference involves a change in the focus of attention which requires a change in a basic assumption. Practical policy analysis requires a look at how regulators actually operate. And to be blunt, they do not set policy with the aim of maximizing discounted profits. More to the point, while they may agree to set a target escapement policy, or as it is more commonly referred, a target stock size policy, they would not use a most rapid approach process of obtaining it. The second part of the paper compares the operation of fee and TAC/ITQs using a process for determining the annual TAC that more closely approximates real world fisheries policies.

AN AGGREGATE VS. A DISAGGREGATED MODEL

While Weitzman uses an implicit model, Hannesson/Kennedy use an explicit model which captures its essence. The analysis here will use the Hannesson/Kennedy framework using the following notation.

N = number of identical boats
d = days fished by each vessel
D= total fishing days=Nd
d_{max} = maximum possible days a boat can fish[a]
C_d = Cost per fishing day
FC = Annualized fixed cost per vessel.
X_{begin} = Stock size at start of season
Y = harvest
X_{end} = Escapement or stock size at end of season

As in the previous articles, it will be assumed that recruitment takes place at the end of the fishing season.

$X_{end}(t) = X_{begin}(t) – Y(t)$
$X_{begin}(t+1) = X_{end}(t) + G [X_{end}(t)]$ (Eq. 1)

G[] is a Schaefer growth function.

<u>An Aggregate Model</u> To set the stage, the basics of the model will be set up in a determinant aggregate analysis. The above notation will apply except that fixed costs will be included in C_d. There are three variables in this model: season effort, D, and X_{end} and X_{begin}. Instantaneous harvest is a function of stock size, the level of effort, what is called the catchability coefficient, q.

y = qXD

Given the assumption that there is no stock growth during the fishing period, -y is the time rate of change in the stock. Therefore the size of the stock at any time during season is:

$X_d = X_{begin}* e^{-qD}$ (Eq. 2)

It follows that cumulative harvest at any time is:

$Y = X_{begin}(1-e^{-qD})$ (Eq. 3)

The marginal harvest per day is:

$\partial Y/\partial D = qX_{begin}*e^{-qD}$

The open access equilibrium level of effort will occur where:

$P\, qX_{begin}*e^{-qD} = C_d$ (Eq. 4)

Given that the other parameters are fixed, seasonal effort is exclusively a function of beginning stock size.

$D = D(X_{begin})$ (Eq. 4a)

While D will vary depending upon the level of X_{begin}, from (2) it will always occur where the ending stock size is the same.
$X_{min} = C_d/(pq)$ (Eq. 5)

The marginal revenue to fishing will always be negative when stock size is lower than this.

A biological equilibrium will occur when growth equals catch such X_{begin} remains constant.
$X_{end} = X_{begin} - Y[D(X_{begin}), X_{begin}]$ (Eq. 6)
$X_{begin} = X_{end} + G(X_{end})$ (Eq. 7)

The simultaneous solution of (4a), (6), and (7) will yield the equilibrium values of the three variables. The dynamics of achieving this equilibrium are quite mundane. If the starting stock size is larger than X_{min}, it will be pushed to X_{min} during the first season. The next year X_{begin} will equal $X_{min} + G(X_{min})$. These will be the equilibrium values. If the initial stock size is less than X_{min}, it will remain at that level until the end of the season at which time growth or recruitment will occur. This will continue until X_{begin} is larger than X_{min}. At that stage there will be one more step to the equilibrium.

The equilibrium values with tax and ITQ regulation programs can be solved as follows. Let X_{goal} represent the optimum ending stock size which is the solution of Weitzman's NPV maximization problem. Given the way the fishery operates, X_{goal} can always be achieved by using a landing tax that satisfies the following equation. See (4).
$(P-t)qX_{goal} = C_d$

The optimal tax is
$t = P-C_d/(qX_{goal})$

Modifying (4), the equilibrium condition for D taking the tax into account, the new function for seasonal effort will be a function of X_{begin} and t.
$D' = D'(X_{begin}, t)$ (Eq. 4b)

The full equilibrium with the tax can be obtained from the simultaneous solution of (4b), (6) and (7). The dynamics of moving from an open access equilibrium to the regulated equilibrium will also be quite simple. D will equal 0 as long as X_{begin} is less than X_{goal}. As soon as X_{begin} surpasses X_{goal}, the new equilibrium will be achieved in the following period.

The same equilibrium will be achieved with a TAC and a perfectly functioning ITQ program. In order to achieve Xgoal in the most rapid manner, the size of the TAC in any period must be determined as follows.
$TAC = X_{begin} - X_{goal}$ if $X_{begin} - X_{goal} > 0$ (Eq. 8)
$= 0$ otherwise.

With an ITQ program, producers will make their operating decisions based on the cost of acquiring, or the opportunity cost of using, annual harvest rights (AHR). The effect is exactly analogous to paying a landing fee. In the market for determining the price of AHR, the maximum bid price will equal the price of fish minus the marginal cost of fish.
$P_{ahr} = P - MC_{fish}$

However, the marginal cost of fish can be derived by dividing the marginal cost of effort by the marginal product of effort. Therefore

$P_{ahr} = P - C_d/(q^*X_{end})$
At the time the TAC is taken, the ending stock size will be X_{goal}. Therefore the equilibrium P_{ahr} will equal the optimal tax, and the ITQ program will generate the same equilibrium values as does tax program.

A Disaggregated Model The above can be expanded into a disaggregated model by taking into account the full implications of the boats that actually produce the fishing days. This means the system variables will be N, d, X_{begin}, and X_{end}. As far as production is concerned this can be accomplished by substituting Nd for D in equations (2) and (3). In that case, the marginal harvest per day *per boat* is:
$[\partial Y/\partial D]/N = qX_{begin} * e^{-qNd}$

Note that in this case, the marginal product per boat will depend upon N as well as on X_{begin}. The marginal revenue equals marginal cost condition that is equivalent to (4) will provide a solution for the annual number of days produced per boat.
$d = d(X_{begin}, N)$ (Eq. 9)

The equation for the ending stock size becomes:
$X_{end} = X_{begin} - Y[N, d(X_{begin}, N), X_{begin}]$ (Eq. 6a)

The equilibrium condition for the fleet size is that vessel profits must equal zero.
$(1/N)\{P*Y[Xbegin, N, d(X_{begin}, N)]\} - d*C_d - FC = 0$ (Eq. 10)

The equilibrium values for the four variables can be obtained from the simultaneous solutions of (6a), (7), (9), and (10) taking into account the limit on the number of days a boat can fish.

Before discussing this solution, consider the graphical representation of the marginal revenue equal marginal cost condition in Figure 1. There will be a different marginal revenue curve for every combination of beginning stock

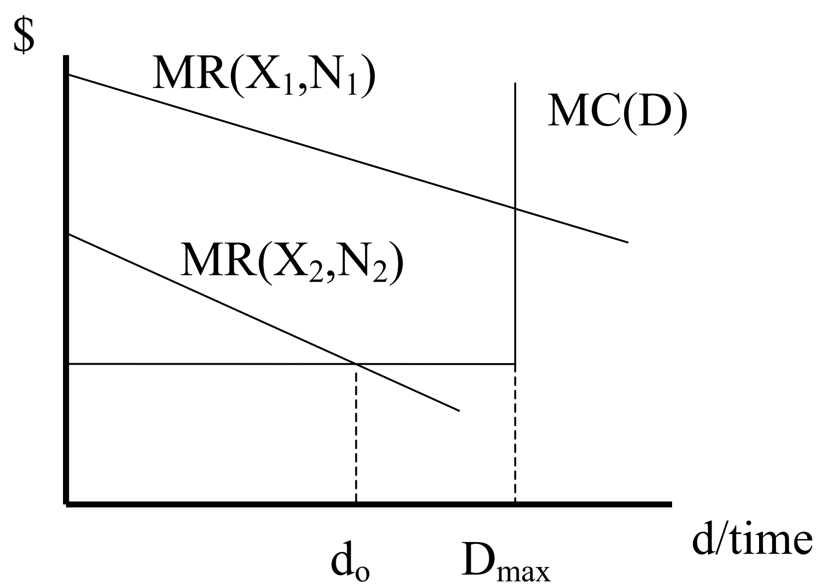

Figure 1. The vessel will stop fishing when the seasonal marginal revenue curve intersects the MC.

size and fleet size, and it will be monotonically decreasing with days fished. The vertical intercept will shift up with stock increases and vice versa. The larger the fleet size, the steeper will be the slope. The marginal cost curve is the horizontal line at C_d, out to D_{max} where it becomes a vertical line. Note that the MR curve is for each and every vessel in the fleet and it shows what happens as they all operate in unison. There is no need to assume that vessel operators make their decisions prior to the season. Each day they will observe MR and as long as it is above MC they will continue to operate. Therefore with the higher curve the boats will operate at D_{max}. They would like to produce more but they do not have the capacity. With the combination of X_{begin} and fleet size on the lower MR curve, boats will operate a d_o. The fleet will stop fishing before the actual fishing period is over because the stock has been pushed to the level where it is not profitable to continue fishing. Unlike the aggregate case, depending on the actual stock and fleet size at any point in time, the stock will not always be pushed down to a level equal to $C_d/(Pq)$

There are two different general types of bioeconomic equilibria. First, if in the solution set to (6a), (7), (9), and (10), the value of d is less than $d_{max,}$ the marginal revenue curve will look like the lower one in the figure. The equilibrium level of X_{end} will equal $C_d/(Pq)$. X_{begin} (X_2 in the figure) will follow from (7). The equilibrium fleet size will be the one that causes the area between the MR curve and the MC curve to equal FC. The equilibrium stock size will be the same as in the aggregate model, but the combination of N and d will not be the one that achieves the equilibrium harvest as efficiently as possible because $d < d_{max}$. This is a different type of open access waste than appears in the traditional model. It follows from the intra-seasonal diminishing marginal productivity of effort.

On the other hand if in the solution set of (6a), (7), (9) and (10), the value of d is greater than d_{max}, the true solution can be found by substituting d= d_{max} for equation (9) and solving for the equilibrium values N, X_{begin}, and X_{end}. The marginal revenue curve will look like the higher one in Figure 1. The solution fleet size, N', must be such that the intraseason rent covers fixed cost, and simultaneously, the level of harvest that is generated by $N'd_{max}$, is equal to the growth of the ending stock size. The equilibrium stock size will be higher than $C_d/(Pq)$, but the fleet will be efficient. That equilibrium stock must be larger in order to generate returns that will cover fixed costs. There is also the special case where the solution value of d just equals d_{max}, in which case the equilibrium in the disaggregated model is analogous to that of the aggregate model. It should be noted that these two types of equilibria are the result of the assumption concerning the MC curve.

The dynamics of achieving the open access equilibrium is more robust with the disaggregate model; a full fledged Vernon Smith model is applicable. [Smith, 1968, 1969].

$N_{t+1} = N_t + \psi\pi_t$

$X_{begin(t+1)} = X_{begin(t)} - Y_t + G(X_{end(t)})$

Fleet size will change according to the size and sign of vessel annual net returns while stock size will change depending upon the relative size of growth and catch. The standard phase diagram will apply. A better comparison of the relative merits of fees and a TAC/ITQ program can be obtained in the context of such an analysis. As the fleet and stock sizes change over time, the marginal revenue curve can intersect the marginal cost curve in both the horizontal and the vertical segments.

Turn now to a comparison of tax and TAC/ITQ equilibrium solutions in the disaggregated model. The mathematics of the tax program equilibrium simply involves adjustments to (6a), (7), (9), and (10) taking into account the presence of the optimal tax. Forgetting about the constraint on d for the moment, the biological part is quite simple because the equilibrium level of X_{end} will equal X_{goal}. Let the equilibrium value of X_{begin} which follows from this be X^*_{begin}. That is, $X^*_{begin} = X_{goal} + G(X_{goal})$. Also, the total number of fishing days necessary to take the stock down from X^*_{begin} down to X_{goal} can be determined using (2). Call this D*. The efficient sized fleet to produce this amount of effort would be:

$N^* = D^*/d_{max}$

The full implications of a tax program can be obtained using a graphical analysis similar to Figure 1. Let the tax corrected marginal revenue curve in Figure 2 be the one for the stock and fleet combination X^*_{begin} and N*. In the special case where area A equals FC, this will be the actual equilibrium and the tax will produce an equilibrium which achieves X_{goal} with an efficient fleet.

However, if area A is less that FC, N* can not be the equilibrium fleet size. The solution will be at a smaller value of N which will cause the curve to rotate upward until the equivalent area is equal to FC. Therefore in this case, the Weitzman tax by itself can not achieve X_{goal}. The tax by necessity, is based on marginal costs in order to affect operator decisions, but it will not allow for fixed cost to be covered if the stock is fished down to X_{goal}. Since there are two control variables, there must be two controls. The tax would need to be combined with an annual vessel subsidy to help the boats cover fixed costs.

The extreme situation in this case would be where the MR with X_{virgin} and N equal to 1 would not allow for the coverage of FC. While the fishery could operate under open access conditions, it could not operate at all with the straight tax program.

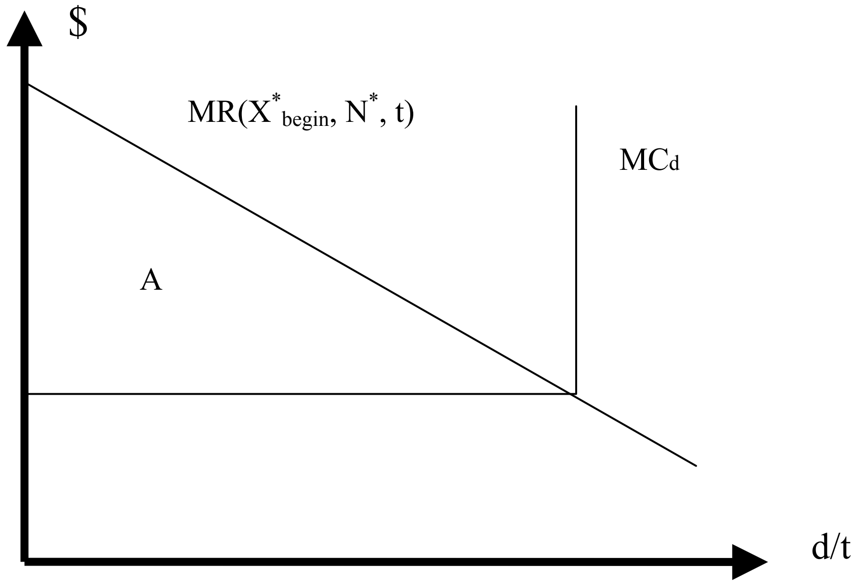

Figure 2. The economic equilibrium occurs when intraseason rents equal fixed costs.

In the opposite case where area A is greater than FC, the equilibrium fleet size would have to be greater that N*. The larger fleet will cause the tax corrected MR curve to rotate downward. The equilibrium will occur were the equivalent area is equal to FC. The tax program would achieve X_{goal} but it would do so with an inefficient fleet. In this case the landing tax would have to be combined with a seasonal vessel tax in order to achieve X_{goal} with an efficient fleet.

Now consider the operation of an ITQ program. The mathematics of the equilibrium solution is more complex because it depends on exactly how the equilibrium price of AHR is determined. However, consider the following heuristic analysis. In short run at least, the market determined value of P_{ahr} would be based on P $-MC_{fish}$ and so it will be equivalent to the optimal tax. And in situations where there is a transition from an open access equilibrium to a regulated equilibrium, this will be beneficial in the short run. The entry and exit of vessels will be a function profits net of the cost of obtaining, or the opportunity cost of using one's own, annual harvest rights. When there are initially excess vessels, they will base their bids purely on variable costs. This will lead to a P_{ahr} that is as high as possible. While this will be tough on participants, it will insure that the strongest price signal is sent that the fleet needs to be reduced. However, as the equilibrium fleet size is approached, there will be incentives for slight modifications in the bidding process for AHR that will cause ITQs to operate efficiently in all cases.

Consider first the case where the optimal tax by itself will cause the fleet to drop to less than N* in order that X_{begin} can be high enough that the boats can cover FC in the presence of the tax. Recall that in this situation, X_{goal} is not achieved and the full TAC is not taken. The market for AHR would never create such a situation. If the AHR market does not clear, there will be modifications to P_{ahr}. While participants will continue to base their bids for AHR on P $-MC_{fish}$, in the long run they will cap their bids such that they can cover FC when the entire TAC is taken. This will lead to a P_{ahr} that is less than the optimal tax and the fee corrected MR curve will rotate downward. However, given the perfectly inelastic portion of the MC_d, it will not change the amount of d produced. Indeed it will just allow for sufficient boats to remain in the fishery that X_{goal} will be achieved.

In the other case where the fleet will become too large with the optimal tax, there will be another type of incentive to correct the problem. If more boats continue to enter based on the highest possible P_{ahr} [P- $C_d/(qX_{goal})$] the vessels will find that at that price all of them will not be able to purchase enough AHR to operate at d_{max}. As such, their average total cost will not be as low as possible because they have not spread fixed cost over the maximum possible number of days. This could lead to one of two bidding strategies. First, they will add a premium to P- $C_d/(qX_{goal})$, which could be covered by the savings in ATC. Second participants could engage in "block" bidding where they bid for enough AHR such that they can operate at d_{max}. The maximum they could bid would be the difference between total revenue and C_d*d_{max} + FC. Such bidding would lead to an average P_{ahr} that was higher than P- $C_d/(qX_{goal})$ and would guarantee that the efficient fleet size was achieved.

In summary, on pure theoretical grounds, a disaggregated model which uses the same basic assumptions as the Weitzman aggregated model, and which gives a clearer picture of fleet operations, suggests that ITQs are superior to tax in the deterministic case. The optimal tax policy requires two controls, (which, in and of itself, makes it more burdensome to administer) and both of these controls require detailed information about fleet costs. ITQs on the other hand only require one control and it is based on biological information.

A MORE RELEVANT PROCEDURE FOR DETERMINING ANNUAL TAC

Like the Weitzman analysis, modern fisheries policy involves setting an X_{goal}, although it is virtually always set on biological rather than economic criteria. However, rather than setting the annual TAC based on a most rapid approach to a goal stock size, as represented by (8), the harvest strategy involves two stock sizes. The first is the X_{goal}, and the second is a minimum stock size, call it X_{safe}, below which the stock should not be allowed to fall. If stock size is below X_{safe}, fishing must cease. If it is between X_{safe} and X_{goal}, fishing is allowed but catch must be kept below stock growth so that the stock will grow to X_{goal} in an acceptable time frame.

While X_{goal} and X_{safe} are technically set on biological ground, fisheries management is a political process. The reality is that both the concept of X_{safe} and the level at which it is set are based on the desire to reduce the chances that a fishery will have to be shut down altogether. In other words, there will be pressures to set X_{safe} as far below X_{goal} as possible.

While there are many ways to specify this type of program, the general idea can be captured in the following which is based on Homan and Wilen (1997).

$$\begin{aligned} TAC &= -m + nX_{begin} \text{ if } -m + nX_{begin} > 0 \quad (\text{i.e., if } X_{begin} > X_{safe}) \\ &= 0 \qquad \text{otherwise.} \end{aligned} \tag{Eq. 11}$$

X_{safe} will equal m/n and above that stock size, the TAC will be an increasing function of X_{begin}. For ease of reference call this the HW TAC. For any value of $X_{safe,}$ it is possible to choose a combination of m and n such that the equilibrium, or X_{goal}, stock size with a HW TAC is equivalent to a most rapid approach program.

Figure 3, which plots the TAC functions against the growth curve, shows the difference between comparable most rapid approach and HW TAC programs. Since the variable on the horizontal axis is X_{begin} while growth is a function of X_{end}, the equilibrium growth for any X_{begin} is that which occurs at the X_{end} which is the solution of equation (7). Note that the slope of the most rapid approach TAC is equal to 1, because everything above X_{goal} is part of the TAC. On the other hand, if X_{safe} is less than X_{goal}, then n must be less than 1, and the greater the difference between the two (i.e., the more reticent regulators are to shut down the fishery), the smaller will be the slope.

There are some significant differences between the most rapid approach and the HW TAC. While they both have the same TAC at the X_{begin} which equals X_{goal} +G(X_{goal}), there are vast differences at other stock sizes. With the

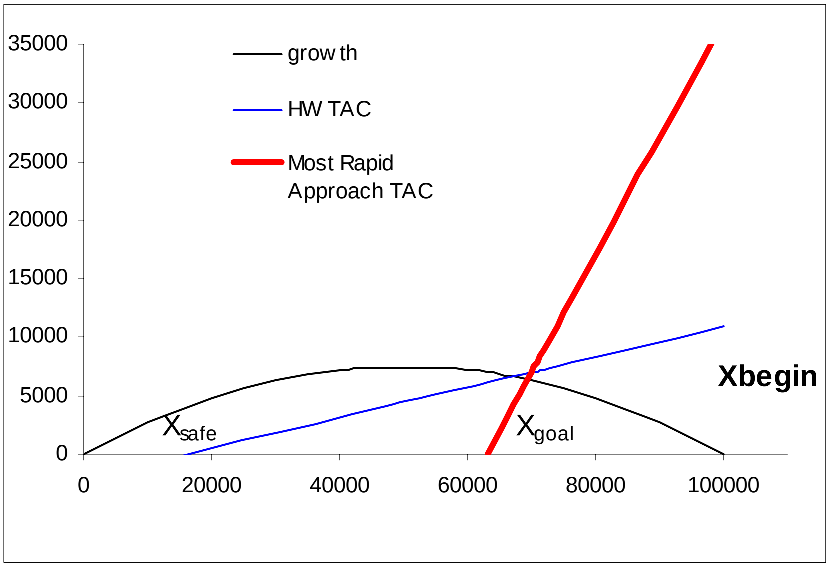

Figure 3. Comparison of most rapid approach and HW TAC programs.

most rapid approach, the range over which there is a complete shut down of the fishery is much larger, and at higher stock sizes, there are much higher catches

There are also significant differences in the way in which taxes and TAC/ITQs will work with an HW TAC program. This is so because X_{goal} is not a constant which was what made fees superior with the most rapid approach under Weitzman's recurrent ecological uncertainty. It will be worthwhile to consider these differences in detail. The difference in the relative success in tax and TAC/ITQ policies in the two programs will depend upon the actual amount of harvest that is generated for a given estimated level of X_{begin} relative to the actual X_{begin}. Let Φ be a positive random variable with a mean equal to 1 which captures the ability of regulators to estimate X_{begin}. Therefore $X_{estimate} = \Phi X_{begin.}$ The differences in the two programs can be demonstrated by plotting the operational potential harvest generated as a function of Φ. As a basis of comparison, Figure 4 shows these relationships for the

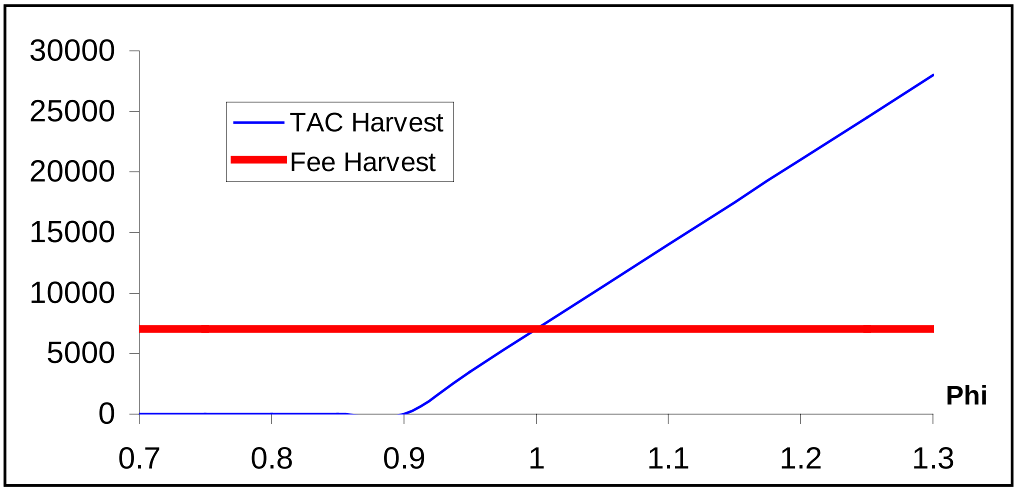

Figure 4. Comparable Harvest levels for different accuracies of estimating X_{begin} with a most rapid policy

most rapid approach TAC. For a given actual X_{begin}, a fee will always generate the same harvest level which will be the difference between the actual X_{begin} and X_{goal}. On the other hand, the operational TAC will be an increasing function of Φ.

$$TAC = \Phi X_{begin} - X_{goal} \quad \text{if } \Phi X_{begin} - X_{goal} > 0 \qquad \text{(Eq. 12)}$$
$$= 0 \text{ otherwise.}$$

Note that the positions of the set of curves will depend upon the particular level of X_{begin}. It is possible that the fee harvest level can be zero, or that the TAC harvest is positive over the full depicted range of Φ. However, the slopes are the important thing to note here. .Now consider the shape of these curves with an HW TAC. When using a fee, the now variable X_{goal} will be:

$X_{goal} = X_{begin} – TAC$

$$X_{goal} = m + (1\text{-}n)X_{begin} \quad \text{if } X_{begin} > X_{safe}$$
$$= X_{begin} \text{ otherwise} \qquad \text{(Eq. 13)}$$

With recurrent ecological uncertainty, the operational X_{goal}, call it X'_{goal} will depend upon how well the beginning stock size can be estimated. Therefore

$$X'_{goal} = m + (1\text{-}n)\Phi X_{begin} \quad \text{if } \Phi X_{begin} > X_{safe} \qquad \text{(Eq. 13a)}$$
$$= \Phi X_{begin} \quad \text{otherwise}$$

The effective harvest under the fee program will be

$Catch = X_{begin} - X'_{goal}$

If $\Phi X_{begin} > X_{safe}$, this will be:

$$Catch = - m + [1\text{-}(1\text{-}n)\Phi]X_{begin} \quad \text{if } X_{begin} - m + (1\text{-}n)\Phi X_{begin} > 0.$$
$$= 0 \quad \text{otherwise.}$$

If $\Phi X_{begin} < X_{safe}$, this will be

$$Catch = (1\text{-}\Phi)X_{begin} \quad \text{if } (1\text{-}\Phi)X_{begin} > 0$$
$$= 0 \text{ otherwise}$$

Consider now the operation of a straight TAC program with the HW TAC. The TAC will be

$$TAC = \text{-}m + n\Phi X_{begin} \text{ if } \Phi X_{begin} > X_{safe} \qquad \text{(Eq. 14)}$$
$$= 0 \quad \text{otherwise.}$$

There are some important differences between the operational TAC functions of the two types of programs. Compare (12) and (14). For any X_{begin}, it is more likely that the TAC will be zero with a most rapid approach because $X_{goal} > X_{safe}$. The very nature of the most rapid approach specifies frequent zero level TACs, and in a stochastic environment, they are more likely to occur. Second the operational TAC will increase faster with increases in Φ with the most rapid approach. It will go up by the full amount of $\Delta\Phi X_{begin}$, while with an HW TAC the operational TAC will increase by $n\Delta\Phi X_{begin}$, where $0<n<1$.

In those periods when $\Phi > 1$, the operational TAC with a HW TAC will be too high and the stock will be pushed below the desired goal. It may allow fishing when the actual $X_{begin} < X_{safe}$. In those periods when $\Phi < 1$, the operational TAC will be too low and the stock will not be pushed down to the desired goal. It may prevent fishing completely even when actual $X_{begin} > X_{safe}$.

The operational harvest levels for fees and a TAC for a range of Φs are shown in Figure 5, again for a given level of X_{begin}. While the TAC curve retains it positive slope, instead of being horizontal the fee harvest curve is negative. While as shown above, the operational TAC will increase by $n\Delta\Phi X_{begin}$ with increases in Φ, the potential

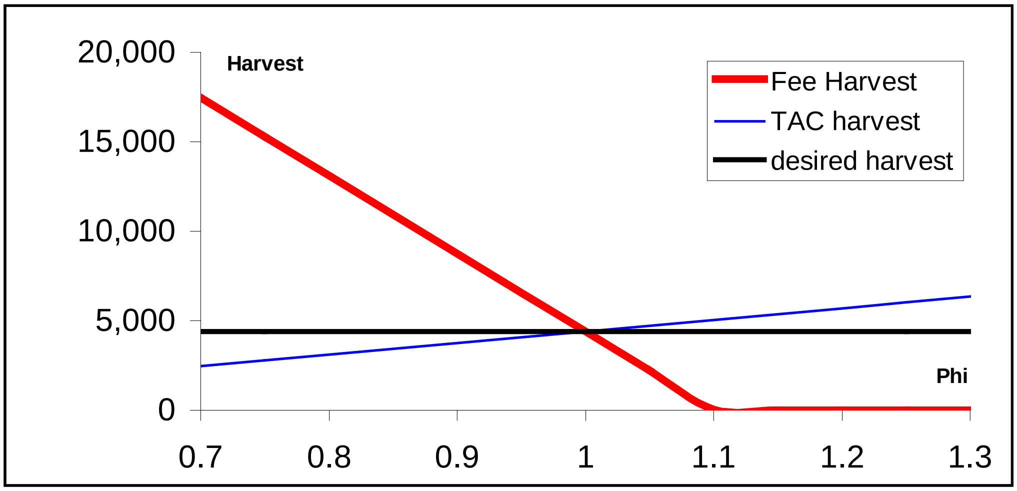

Figure 5. Comparable Harvest Levels for different accuracies of estimating X_{begin} with a HW TAC Policy

operational harvest with fees will fall by $(1\text{-}n)\Delta\Phi X_{begin}$. This particular set of curves is based on a relatively low level of n for the reasons described above. The reason operational harvest can fall to zero is that when stock size is over-estimated, the estimated X_{goal} can be larger than X_{begin} and so fishing will not be profitable with a fee designed to achieve X_{goal}.

By comparing Figures 4 and 5, it is clear that the HW TAC will produce a different set of landings for both fees and TAC/ITQ than will the most rapid approach. The real issue of course is how these differences will change the expected value of the NPV of the harvest streams. Will fees always be superior to using a TAC/ITQ program? There are several ways of looking at this question. First, note than as n is reduced, the TAC curve in Figure 5 comes closer to approximating the horizontal line generated by a fee program with the most rapid approach TAC. At the same time the fee line becomes steeper. The reverse is true, however, when n approaches 1. Since it is the horizontal catch curve for fees which makes fees produce a higher NPV with a most rapid approach, it follows that the lower the value of n (i.e., the larger the distance between X_{safe} and X_{goal}, the more likely is a TAC/ITQ to generate a higher NPV with an HW TAC.

Another factor to consider is how often the fishery will erroneously be shut down. This will have a significant effect on NPV. Recall that with an HW TAC the fishery is supposed to shut down when X_{begin} is less than or equal to X_{safe} The question is how often will it be shut down when the actual X_{begin} is greater than X_{safe}. In the case of fees, the fishery will be shut down when the value of X'_{goal} in equation 13 is greater than or equal to X_{begin}. Some relatively simple algebra will show that the cut off point for this is when
$\Phi = 1/(1\text{-}n) \; \text{-}m/[(1\text{-}n)X_{begin}]$

When X_{begin} equals X_{safe}, m/n, the value of Φ is 1. The relevant question is what value Φ must take on to shut down the fishery when X_{begin} is greater than X_{safe}. The answer will depend upon the value of n. Table 1 shows the critical value for Φ for various combinations of n and beginning stock sizes relative to X_{safe}. For example, if n =.2, a Φ of 1.16 will shut the fishery down when the actual X_{begin} is three times larger that X_{safe}. That is an error of plus 16% will shut the fishery down even when the actual X_{begin} is three times larger than X_{safe}. In the real world, the errors in estimating stock size are frequently in the range of plus or minus 30%. Therefore when n is low, given the real world ability to estimate stock size, a fee policy will frequently shut the fishery down even when X_{begin} is much larger than X_{safe}.

	n =.1	n = .2	n =.3	n =.4
2xXsafe	1.055	1.125	1.214	1.333
3xXsafe	1.074	1.166	1.285	1.444
4xXsafe	1.083	1.187	1.321	1.500
5xXsafe	1.088	1.200	1.342	1.533
6xXsafe	1.092	1.208	1.357	1.555
7xXsafe	1.095	1.214	1.367	1.571

Table 1 Critical value of Φ necessary to shut fishery down for various combinations of n and stock size relative to X_{safe} for fees in HW TAC program

The chances for errors shutting down the fishery are different with a TAC. See equation 14. The fishery will shut down whenever ΦX_{begin} is less than or equal to X_{safe}. Using the same sort of logic as above, the relationship between a beginning stock size and the Φ that is necessary to shut down the fishery is shown in Table 2. In this case it requires a 67% error to close the fishery when X_{begin} is three times X_{safe}. The estimated stock is 33% of the actual stock. These values do not depend upon n. By comparing Tables 1 and 2, it can be seen that for lower values of n for any stock size it takes a takes smaller estimation errors to erroneously shut down a fishery with a fee than with a TAC/ITQ. Therefore it is likely that in real world TAC programs that do not rely on a most rapid approach to the X_{goal}, that fees will not be superior to TAC/ITQ. There greater the difference between the programs in terms of the range of stock size where the fishery will be shut down, the more likely this is to be true.

2xXsafe	0.500
3xXsafe	0.330
4xXsafe	0.250
5xXsafe	0.200
6xXsafe	0.166
7xXsafe	0.142

Table 2. Critical value of Φ necessary to shut fishery down for various levels stock size relative to X_{safe} for TACs in HW TAC program.

Summary and Implications for Further Work

The Weitzman analysis of the relative ability of fees and TAC/ITQs to maximize NPV is correct given his assumptions. However, by using a disaggregated model and by introducing a more realistic system for setting the TACs, the claims of superiority can be challenged.

Several issues that follow from the above analysis raise interesting questions for future research. First, in the context of a disaggregated Smith dynamic model, the fleet size will vary over time as the fishery adjusts to a TAC program. Therefore, contrary to the aggregate model, it is possible that at certain times there will not be sufficient harvesting capacity to take the potential allowable harvests. It would be interesting to see how this affects the conclusions especially since the most rapid approach TAC places more severe restrictions on vessels.

In addition, it would be interesting compare fees with TAC/ITQ programs using biological criteria. The fact that fees are more likely to shut a fishery down when stock size is overestimated may be more conducive to the precautionary approach to management.

REFERENCES

Hannesson, Rognvaldur and John Kennedy, 2003, Landings Fees vs Fish Quotas, manuscript Norwegian Business School, Bergen, Norway.

Homans, F. R. and J. E. Wilen, 1997, A Model of Regulated Open-Access Resource Use, *Journal of Environmental Economics and Management*, 32, pp. 1-21.

Smith, V. L., 1968, Economics of Production from Natural Resources, *American Economic Review*, 58, pp. 409-431.

Smith, V. L., 1969, On Models of Commercial Fishing, *Journal of Political Economy*, 77, pp. 181-198

Weitzman, Martin L., 2002, Landing Fees vs Harvest Quotas with Uncertain Fish Stocks, *Journal of Environmental Economics and Management*, 43, pp. 325-338.

ENDNOTES

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[a] The standard assumption of a constant cost per unit of effort has been maintained. Therefore it necessary to specify a d_{max} or all effort could be produced by one boat.