LANDING FEES VERSUS FISH QUOTAS[i]

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ABSTRACT

The relative efficiency of landing fees versus quota controls to achieve given escapement levels is examined. The criterion is profit per year over a given time horizon. The model employed is a discrete version of the logistic model where growth is influenced by a random variable. Simulations are used to compare landing fees and quota controls under imprecise stock estimates, variable availability of fish, and random fish prices. While ecological uncertainty combined with imprecise stock estimates favors fee control, as shown by Weitzman, the opposite can be the case under uncertainty about the availability of fish or fish price.

Keywords: Landing fees, quotas; uncertainty;

INTRODUCTION

Optimal fisheries management involves fishing down a stock over a certain time interval to the desired level and then leaving it to grow and reproduce, starting with a replenished stock in the next fishing period. A straightforward application of this is to set a total catch quota for the industry equal to the difference between the stock at the beginning of the fishing period and the stock to be left behind at the end (usually called escapement), if necessary with an allowance for stock growth and decay during the fishing period. There is a problem with this approach if the size of fish stocks cannot be assessed with certainty at the beginning of the fishing period when the quota is set. The escapement target would not in general be achieved, and under the worst of circumstances a stock could be depleted below its threshold level of viability and become extinct.

The advantage of management by landing fees is that it could make the industry self-regulating. An appropriate landing fee would entice the industry to stop fishing when the marginal cost of fish catches has risen to a level equal to the market price less the landing fee. If this is to ensure that the appropriate target escapement will be reached, the marginal cost of fish catches must depend on the level of the exploited fish stock in a stable way. Fishermen observe their marginal costs and thus indirectly the stock level, and if the landing fee is set appropriately, they will leave the desired stock level behind when it becomes unprofitable to continue fishing.

It is easy to see that this mechanism will not work if the marginal cost of fish does not depend on the level of the exploited stock. In some fisheries this appears to be true or nearly so. For species such as herring and capelin it has been found that the unit cost of fish is only weakly or possibly not at all related to the size of the exploited stock (see, e.g., Bjørndal, 1987). If this stock-cost relationship is weak and there is some uncertainty involved in how the stock affects the marginal cost function, the fee solution is likely not to work well.

There are other problems with the landing fee solution. The fisheries managers must know how the industry reacts to changes in landing fees. This is a tall order. Fishermen might react to an increased landing fee by trying harder to make ends meet, but even if their reaction is in the expected and desired direction its magnitude is uncertain. There is also technological change to account for; managers may not be aware of the efficiency of new boats or fishing equipment and gear. Over time managers may learn how fishermen react to changes in fees. While technological leaps sometimes occur in the industry, technological change may under normal conditions be predictable and occurring at some accustomed rate.

In this paper we assume that managers know how the industry will react to changes in landing fees but focus instead on uncertainties that will shift the marginal cost functions of fishermen in unpredictable ways. These uncertainties are of two kinds. First, there is uncertainty with respect to the availability of fish. Fish are easier to catch under certain conditions than others, due to better weather, different conditions in the sea, etc. Such variations are difficult to predict. Second, there is uncertainty with respect to what price the fishermen may get for their catch. As will be seen, both these uncertainties affect the relative efficacy of landing fees versus fish quotas and, as it turns out, in a similar way. Both these uncertainties translate into uncertainty about fishermen's normalized marginal costs of fish and the level to which they will deplete the fish stock.

To our knowledge, landing fees are nowhere used as regulatory instruments in fisheries while fish quotas have become quite widespread.[ii] This does not necessarily mean that landing fees are inferior to quotas; their absence could be due solely to an absence of imaginative thinking among managers and opposition in the industry to paying fees. Landing fees would certainly seem to be just as feasible a solution as a fee or a tax levied upon any other production in order to avoid negative externalities. Landing fees would, however, run into some of the same problems of monitoring and enforcement as fish quotas; the incentive to avoid paying a landing fee is similar to the incentive of avoiding having one's catch subtracted from one's allotted quota, but landing fees would not give any incentive to throw away valuable fish at sea, as quotas do.

EARLIER LITERATURE ON THIS SUBJECT

This paper is inspired by the article by Weitzman (2002) on landing fees *vs* harvest quotas. In this paper, Weitzman focussed on ecological uncertainty, i.e., uncertainty about recruitment of fish (or more generally the relationship between the stock left after fishing in period *t* and the stock emerging in period *t*+1 through a general growth and decay process). Using dynamic programming, he proved that "the 'as if myopically omniscient' optimal fisheries policy is a most rapid approach to constant escapement level …" (p. 335). He further showed that, in this setting, landing fees are superior to quotas set on the basis of uncertain estimates of the current stock level.

As acknowledged by Weitzman, there are other types of uncertainties in the fishery which could reverse this conclusion. "A formal analysis of exactly how 'ecological uncertainty' and 'economic uncertainty' interact to determine the optimal choice of fishery regulatory instruments involves a complicated tradeoff that is properly the subject of another paper" (Weitzman, 2002, p. 337). The purpose of this paper is to examine this tradeoff. Our approach follows Weitzman's in that it is explicitly dynamic, but we have found it necessary to resort to a numerical but still quite general model.

Jensen and Vestergaard (2003) have also addressed the question of fees versus quotas as regulatory tools in fisheries. Their paper is, however, more closely related to Weitzman's earlier paper on prices versus quantities (Weitzman, 1974). The main difference between our paper and the one by Jensen and Vestergaard is that we explicitly track the development of the fish stock over time. This makes it possible to obtain more clear cut results and to account for stock extinction, which may happen under some inauspicious circumstances.

Our specification of costs and benefits also differs from the ones used by Jensen and Vestergaard. In some respects their treatment is more general. They allow for consumer surplus while we assume a price that is independent of landings, but possibly influenced by random events. They use a marginal cost function which depends both on the size of the fish stock and the catch of fish while in our case the marginal cost of fish caught depends only on the size of the stock. As shown in the next section, an assumption of a constant cost per unit of effort, which is an index of the use of factors of production, implies a unit cost of fish that is independent of the catch rate of fish but dependent on the size of the exploited stock except in the special case of a schooling fishery. A rising unit cost of effort could happen as a result of an inhomogeneous fleet or differences in fishermen's skills or a change in the intensity with which boats are being used (longer hours per day, more trips during the week, etc.). We will ignore consumer surplus and rising unit cost of fishing effort, as these considerations are of second order importance for the relative merits of quota versus fee control, which depend critically on how the marginal cost of fish depends on the size of the exploited stock. Hence we will focus on the case discussed in Weitzman's 2002 paper, which states that "[T]he only critical assumption being made here is that $\pi'(x) > 0$ for all $x \geq 0$, which corresponds to the standard assumption that $c'(x) < 0$" (Weitzman, 2002, p. 329), where *x* denotes the fish stock

Our cost specification allows us to derive clear results for what Jensen and Vestergaard, following Neher (1990), call search fisheries and were intractable in their model. Furthermore, with our specification of the cost function it follows that the fee solution does not work in a schooling fishery without search costs. In that case the stock would be wiped out immediately unless the price of fish or the cost of fishing are sufficiently sensitive to the quantity landed and the effort applied, respectively (Hannesson, 1993, pp. 43 - 45). A quota control also is problematic in that case, since it will also lead to stock extinction in finite time if the error in stock assessment is too great. Still, this may contribute to explaining what Jensen and Vestergaard (2003, p. 422) find surprising, namely that no real world fisheries appear to be regulated by landing fees.

Earlier papers (Koenig, 1984a, 1984b; Androkovich and Stollery, 1991, 1994) have also addressed the issue of landing fees versus quotas in fisheries. Koenig (1984a) follows the tradition of Weitzman's *Prices vs. Quantities* (1974) and considers different types of uncertainties on the benefit versus cost side and their implications for the advantage of landing fees over quotas or vice versa. Koenig did not explicitly consider fish quotas based on erroneous estimates of fish stocks, nor did he explicitly consider the role of the fish stock as a factor of production. He used a linearized growth function, in order to obtain a solution to his dynamic programming problem. Androkovich and Stollery (1991) also, and for the same reason, used a linearized growth function and a very special production function. Their specifications of uncertainty are similar to Koenig's (1984a). The contribution of this present paper is that it deals simultaneously with uncertainty about stock estimates, availability of fish, and prices, and does so with a non-linear growth function that allows, inter alia, the consideration of stock extinction as a result of overfishing.

THE MODEL

We assume that the fish stock is managed by setting a target escapement each year, and that the criterion of success is the sum of annual net benefits over 100 years. Net benefits are, for simplicity, not discounted, since it does not seem likely that alternative discount rates will affect the choice between the two control instruments we are dealing with. Discounting would make the results sensitive to the initial stock size and the realization of the stochastic variables early in the period, but would hardly affect the outcomes from fee versus quota control in a systematic way. The target escapement is set at the level optimal for the deterministic case and the stochastic case of 'ecological uncertainty', the case that Weitzman focuses on.

We use the same target escapement for comparing the performance of quotas and fees for other sources of uncertainty. To find the truly optimal escapement would require a stochastic dynamic programming approach. This we hope to address in a separate paper. As a first approach to investigating the relative merits of quotas and fees for various sources of uncertainty, it seems reasonable to model regulators as targeting the escapement stock which is optimal for the deterministic case, or the case where all stochastic variables are set at their mean levels.

The information structure assumed is as follows. Fishery managers set fish quotas on the basis of imperfect estimates of the fish stock at the beginning of the fishing period, or, alternatively, landing fees without knowing the price or the availability of fish in the coming period. Fishermen, on the other hand, make their decisions about how much to fish after fish prices have become known and on the basis of the actual availability of fish. The actual availability of fish manifests itself as a certain realized catch per unit of effort. Fishermen are assumed to deplete the fish population in any given period until the catch per unit of effort has fallen to a level where further depletion is not profitable. This behavior among fishermen is to be expected under open access with many fishermen exploiting a common stock.

It is worthwhile mentioning that the information structure assumed does not imply that fishermen are better informed about the size of fish stocks than the management authority. What fishermen observe and management does not observe, except with some time lag, is catch per unit of effort (catch per hour or fishing day). If the catch per unit of effort is a linear and deterministic function of the size of the exploited fish stock, this would provide timely information to the fishermen about the stock size. But if this relationship is stochastic this information will not be correct, and if it is non-linear the fishermen would presumably be hard put to interpret it correctly. The problems this poses for the fee solution is what we focus on in this paper.

To deal with the problem in as simple a framework as possible, we shall use the discrete-time variant of the logistic model:

$$(1) \qquad X_{t+1} = S_t + aS_t\left[1 - S_t / K\right] + \varepsilon_t S_t \qquad S_t = X_t - Y_t$$

where S_t is escapement (stock left after fishing in period t), X_t is the stock available at the beginning of period t, Y_t is the quantity fished in period t, a is the intrinsic growth rate, K is the carrying capacity of the environment, which we normalize to 1 for simplicity, and ε_t is a random environmental variable influencing growth. We assume that ε is normally distributed with an expected value of 0 and a constant variance.[iii]

At the beginning of each period, managers estimate the size of the returning stock (X). We assume that their stock estimates (X_E) are lognormally distributed, so that

$$\ln X_{E,t} = \ln X_t + \varepsilon_{X,t}$$

where ε_X is normally distributed with a constant variance σ_x^2 and an expected value of zero.[iv] Under a quota regime, managers set a catch quota equal to the difference between the estimated stock size at the beginning of each period and the target escapement (S^*). We assume that the managers are unable to predict the environmental conditions in the period that is just beginning and unable to revise their decisions until the fishing is over. They may therefore be expected to set the target escapement on the basis of normal growth conditions reflected by the expected value of ε and equal to the optimal escapement in a deterministic world. If managers were able to forecast the environmental conditions correctly the optimal target escapement would be affected by the environmental conditions, with fishing being less intense under conditions favorable for fish growth, in order to increase the available stock at the beginning of the next period (on the consequences of being able to predict growth conditions, see Costello, Polasky and Solow, 2001).

Under fee management, managers attempt to realize the target escapement by setting a landing fee that entices fishermen to stop fishing when this target has been reached. For this to be possible, the cost per unit of fish caught must be a declining function of stock size. To derive a cost function, we use the familiar relationship

$$y = Eqx^b \tag{2}$$

where y is the catch flow (catch per unit of time), E is fishing effort, x is the size of the stock being fished, and q is a coefficient reflecting the availability of fish (how easy they are to catch). For $b > 0$ the catch per unit of effort (y/E) will rise and decline with the stock. We shall refer to b as the stock elasticity (i.e., the elasticity of the catch with respect to the stock). The case $b = 1$ is popular in the literature but holds only under rather special circumstances; i.e., when the density of the stock is proportional to the size of the stock, as would obtain if the stock were always evenly distributed over the same area. Many fish stocks are known to behave differently, their area of distribution contracting as the stock declines (see, e.g., Bailey and Steele, 1992; Kawasaki, 1992), and some fish occur in shoals. In such cases the stock elasticity will be close to zero, as some empirical work has confirmed (e.g., Bjørndal, 1987). Another possibility is that the value of b for any given stock varies for environmental reasons. It appears, for example, that demersal stocks like cod can concentrate in a smaller area as a result of colder ocean temperature, a phenomenon which may precipitate their decline. We shall not pursue the implications of a stochastic b any further here.

Given this catch function,[v] with c being the operating cost per unit of effort, the operating cost per unit of fish caught at each point in time will be $cE/qEx^b = c/qx^b$. Therefore, the operating profit (π) over one period will be

$$\pi = \int_S^X \left[p - c/qx^b \right] dx \tag{3}$$

where p is the price of fish, assumed independent of the quantity caught, X is the stock level we start with, and S is the stock left behind (escapement). Fishermen will stop fishing when $x = (c/pq)^{1/b}$. This illustrates how the landing fee works; the managers just have to set p (or c) at an adequate level so that the fishermen stop fishing when the stock has reached the target escapement level S^*.

The uncertainty regarding the availability of fish manifests itself in variability of q. This means that the effect of any given landing fee (or a fee on fishing effort) is impossible for managers to predict with certainty, even if they know c, as the escapement level attained will depend on the realized value of the availability coefficient (q). The effect of uncertainty about the price of fish (p) affects S in the same way, as long as p and q are identically distributed, but will have a somewhat different impact on the single period profit (cf. Equation (3)). Managers will try to achieve a given target stock level S^* by imposing a landing fee so that the price received by the fishermen will be below the market price, but if they cannot predict the market price and base the landing fee on a "normal" price, the price received by fishermen will vary in the same way as the market price.

An additional problem in determining S^* by a landing fee is that managers might not know the fishermen's c. This will be ignored here, as already discussed.

Evaluating the integral in (3), we get

$$\pi = p(X - S) - (c/q)\left[\ln(X) - \ln(S)\right] \qquad \text{for } b = 1$$

$$\pi = p(X - S) - (c/q)\left[X^{1-b} - S^{1-b}\right]/(1-b) \qquad \text{for } 0 < b < 1 \tag{4}$$

$$\pi = (p - c/q)\left[X - S\right] \qquad \text{for } b = 0$$

From (1) and (4) we can find the optimal steady-state escapement S^* from the first order condition for profit maximum in a deterministic model without discounting, with p and q normalized at unity:

$$a(1-2S^*) - c\left[\frac{1+a(1-2S^*)}{\left[S^*\left(1+a(1-S^*)\right)\right]^b} - \frac{1}{S^b}\right] = 0 \qquad \text{for } 0 < b \leq 1$$

(5)

$$S^* = \tfrac{1}{2} \qquad \text{for } b = 0.$$

We shall assume that q and p are lognormally distributed:[vi]

$$\ln q_t = \varepsilon_{q,t}$$

(6)

$$\ln p_t = \varepsilon_{p,t}$$

where ε_q and ε_p are normally distributed with an expected value of zero and a constant variance. Hence, under normal conditions, $q = 1$ and $p = 1$. This normalization only affects the units in which effort and its cost are measured. We assume that the fishery managers cannot observe q and p but set the landing fee on the basis of the value of these variables under normal conditions (i.e., with both ε's equal to zero).

SIMULATIONS

To compare fee versus quota management we ran simulations of the above model. For each set of parameters we ran 100 simulations, with each simulation covering 100 periods, which it is convenient to refer to as "years." The criterion of success is the operating profit per year, as given by Equation (4), produced by each simulation. This criterion is not unproblematic. The profits as given by Equation (4) are revenues in excess of operating costs. It is operating costs which determine at what point it is no longer worthwhile to continue fishing; in a discrete time model where the processes of catch versus growth and recruitment do not occur simultaneously but sequentially, fishermen will go on fishing as long as the revenue flow is greater than the flow of operating costs. Fixed costs, such as capital costs, are of course irrelevant to this decision, so the profit as defined in Equation (4) is in reality operating surplus, which includes contribution towards paying fixed costs. Under open access one would expect that any profits would be absorbed by capital costs. This is what typically happens when fisheries are controlled by nothing other than an overall quota; fleet capacity increases and the fishing season becomes shorter until profits have been absorbed by capital costs. Fee control would have the advantage vis-á-vis control by a total quota that the profit would be reduced and there would be less room for increasing the total capacity of the fleet. A detailed analysis of whether fee control would result in an optimal investment in fishing boats is a question worthwhile in itself, but it requires a different approach, and we leave it for later research. The quota control we have in mind is a kind of control which provides incentives for the industry not to overinvest in fishing fleet capacity, such as individual transferable quotas.[vii]

Expected operating profit per year is not the only possible criterion by which to compare the outcomes of landing fees versus quotas; variability of profit would also be important if managers were not risk neutral. Neither approach is unambiguously better in that respect; unsurprisingly the method yielding the highest annual operating profit is often the one with the highest variability of the same.

The parameters being varied between the sets of simulations are σ_X, σ_q and σ_p, i.e., the variability of the stock estimates, the availability of fish, and the market price of fish. For each variation in σ_X we hold σ_q constant at 0.1 with a constant price. When varying σ_q (σ_p) we hold σ_X constant at 0.1 and regard p (q) as deterministic.[viii]

Each simulation starts in year one with a stock level equal to the target stock level (the returning stock resulting from the optimal escapement in year zero in a deterministic model). From year one on we draw values of the three random variables ε, ε_X and ε_q (or ε_p if q is deterministic) with a random number generator. Since quota management and fee management result in different catches the stock development will differ under the two regimes but, needless to say, both face the same random values of ε and q in each period.

RESULTS

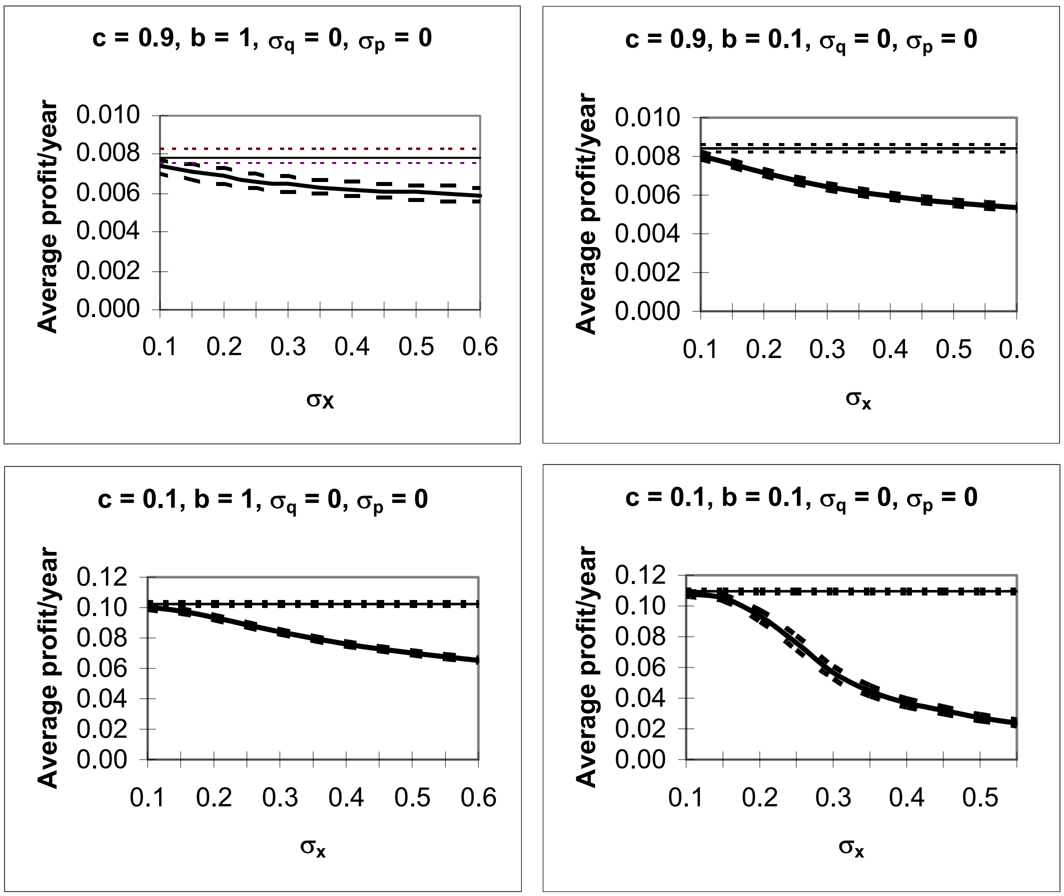

Figure 1
Average profit per year over a 100 year horizon obtained in 100 simulations under quota (thick lines) versus fee (thin lines) management for different variances of the stock estimate (σ_X) and with no variance in availability (σ_q = 0) or the price of fish (σ_p = 0). Dotted lines show 95% confidence interval.

We begin by confirming Weitzman's result that fee control would be better than quota control if the only uncertainty involved concerns stock assessment. Figure 1 shows the average profit per year under fee (thin lines) versus quota control (thick lines) and the 95% confidence intervals (dotted lines). Four cases are reported, involving combinations of high versus low costs of fishing (c) and high versus low stock elasticity (b). It is the latter parameter (b) which determines the sensitivity of the unit cost of fish to changes in the fish stock, with b = 1 implying high sensitivity and b = 0 implying that the unit cost of fish is independent of the stock. As expected, the fee control is more profitable in all cases, and the advantage of the fee control increases as stock assessment becomes less reliable. Furthermore we may note that the average annual profit under fee control is independent of the variability of the stock estimates. In other words, under these assumptions the fee control would be an error-free method of controlling the stock.

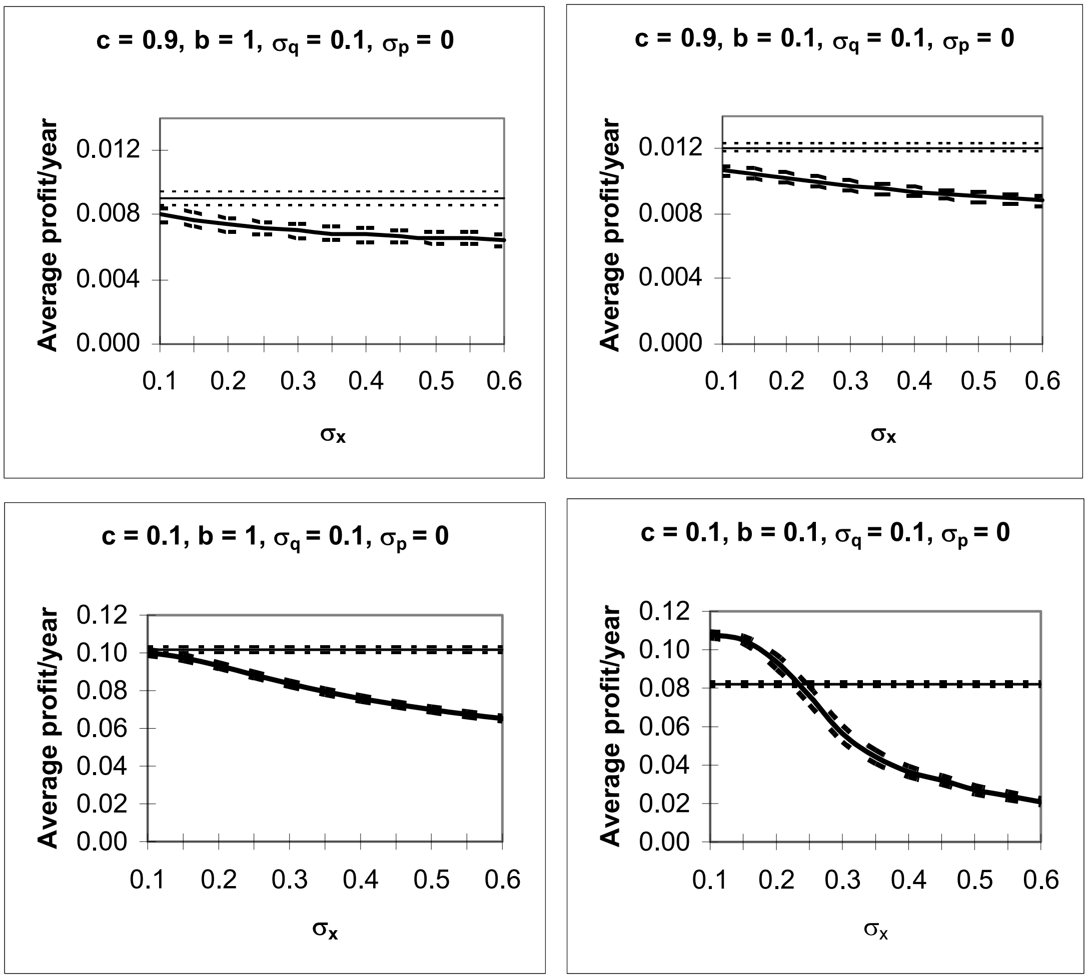

Figure 2
Average profit per year over a 100 year horizon obtained in 100 simulations under quota (thick lines) versus fee (thin lines) management for different variances of the stock estimate *(σ_X)* and with a given variance of availability (σ_q = 0.1). Dotted lines show 95% confidence interval.

Figures 2 - 4 show how the advantage of fee versus quota control is affected by changes in the variance of the stock estimate, fish availability, and the market price of fish. As expected, the stock elasticity (*b*) turns out to be critical, but the cost parameter (*c*) also plays a role for which turns out better, fees or quotas.

Looking first at the effect of increasing uncertainty about stock estimates (Figure 2), we see that the quota regime generally gives a poorer result than the fee regime. The greater the uncertainty with which the stock is estimated the worse the quota regime performs. This is of course due to the fact that the target escapement will often be missed, and when the stock estimates are unduly optimistic the stock will be knocked down to a low level from where it will take a long time to recover. Things are particularly serious when both the fishing cost and the stock elasticity are low (*b* = 0.1 and *c* = 0.1). Low fishing costs make it profitable to knock the stock down to a low level, while a low stock elasticity means that the unit cost of fish is not very sensitive to a fall in the stock level. A coincidence of high fishing costs and stock elasticity (c = 0.9 and b = 1) provides some protection against too optimistic quotas; when the stock is small it simply will not be profitable to take the entire quota.

From Figure 2 we also note that the average profit per year under quota control is relatively little affected by increased uncertainty about stock estimates when the cost of fishing and the stock elasticity are both high. The reason is that in this case both nature and economics protect the stock against human misjudgment. If an optimistic stock estimate leads managers to set an unduly high catch quota, the fishery will become unprofitable long before the optimistic quota has been taken. The strength of this effect depends on the cost of fishing (through the parameter c) and how sensitive the catch per unit of effort is to the size of the stock, which depends on the stock elasticity (b). If the catch per unit of effort stays high irrespective of whether the stock is large or small and the cost of fishing is low, this protective effect will be weak. In the event that fishing costs nothing or the stock elasticity is zero this effect disappears and neither nature nor economics offer any protection. Simulations show that with a zero cost of fishing or zero stock elasticity the stock becomes extinct well within the 100 years time horizon when the variance of the stock estimates becomes too large. The problem is, however, that the fee control also becomes non-operational if the stock elasticity is zero, as it works through a falling catch per unit of effort as the stock is depleted.

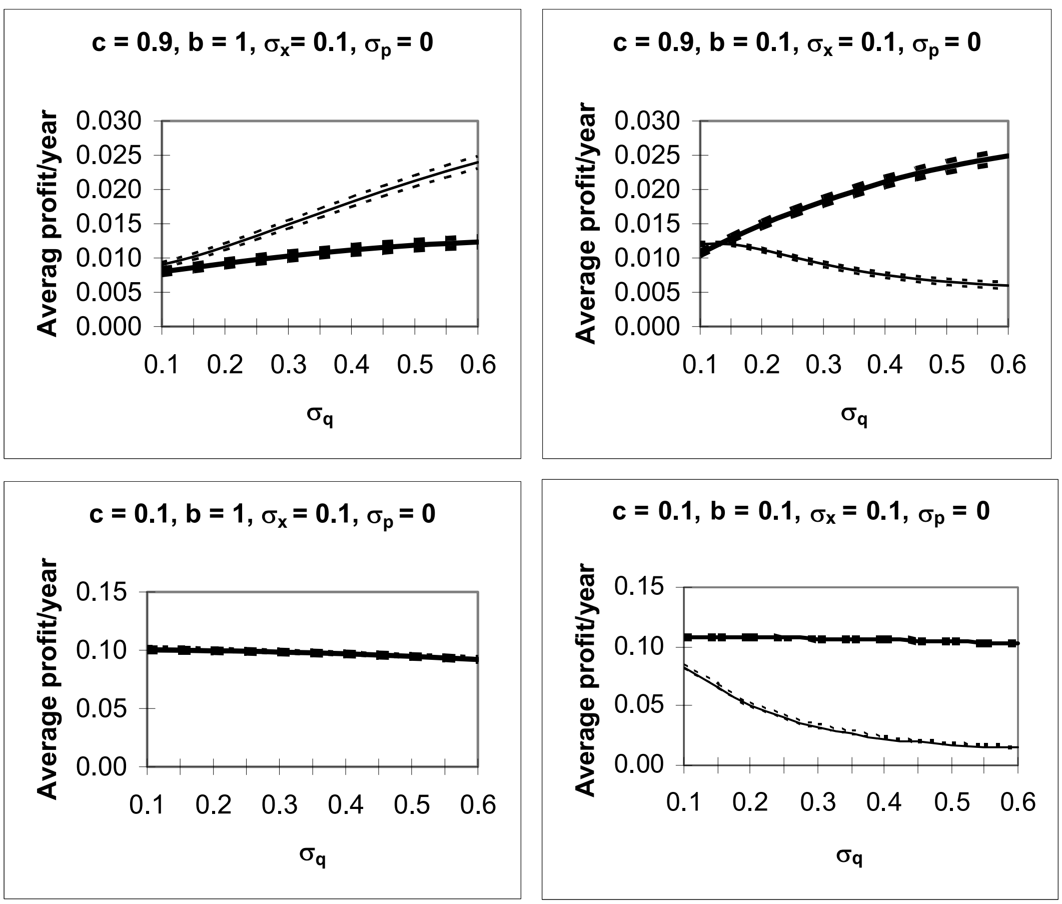

Figure 3
Average profit per year over a 100 year horizon obtained in 100 simulations under quota (thick lines) versus fee (thin lines) management for different variances of fish availability (σ_q) and with a given variance of stock estimate (σ_X = 0.1). Dotted lines show 95% confidence interval.

A final observation about Figure 2 is that there are cases when the quota regime outperforms the fee regime. This occurs for low fishing costs and stock elasticity (c = 0.1 and b = 0.1) and a low variance of the error in estimating stock size ($\sigma_X < 0.25$). This points to the fact that the fee method is not perfect; in the simulations in Figure 2 there is a small variance in availability ($\sigma_q = 0.1$), which means that the fee method will not guarantee that the target escapement will be realized.

The consequences of increasing the variance of the availability coefficient (σ_q^2) are illustrated in Figure 3. The first thing to note is that fee control is generally inferior to quota control when the stock elasticity is low (b = 0.1). In this case the effect of increasing the variability of q on profits is dramatically negative with fee control; the profit per year with fee control falls far below the profit per year under quota control as σ_q increases. To understand why, recall that fee control works through implicitly determining a stock level at which further fishing becomes unprofitable. When managers do not know the value of q they will often miss their target escapement, even if they know everything else they need to know. If q is above normal the catch per unit of effort will be high, and fishermen will deplete the stock below the target escapement. The difference between the target escapement and the escapement fishermen leave behind will be greater the lower are their fishing costs (c) and, in particular, the less sensitive the catch per unit of effort is to a depletion of the stock (low b).

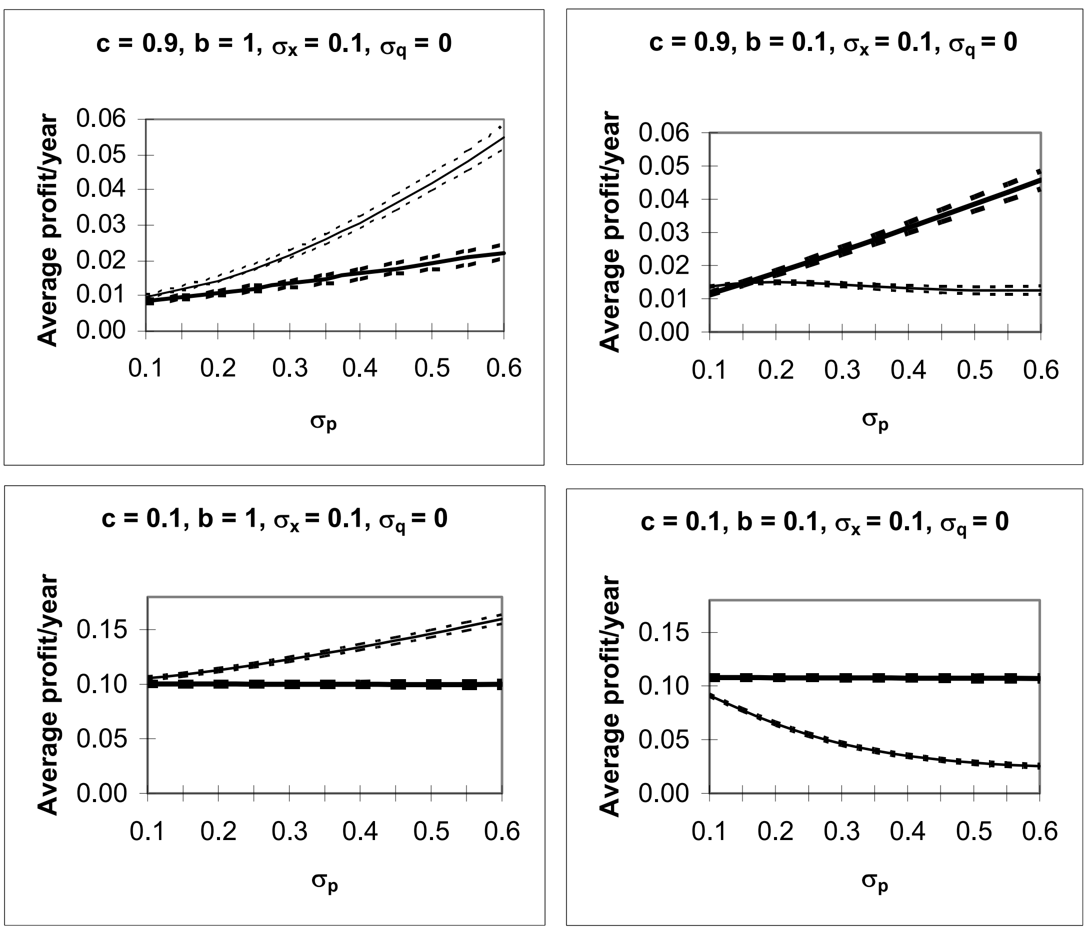

Figure 4
Average profit per year over a 100 year horizon obtained in 100 simulations under quota (thick lines) versus fee (thin lines) management for different variances of fish price (σ_p) and with a given variance of stock estimate (σ_X = 0.1). Dotted lines show 95% confidence interval.

Another thing to note is that the variability of q also affects the profitability of the quota management regime, unlike the case of fee management and increased error in stock assessment. The reason is that the availability of fish affects the actual catch under a quota regime whereas the catch under a fee regime is independent of any stock assessment error. When the availability is poor, all of the quota will not be taken, as it will be unprofitable to deplete the stock as necessary to take the whole quota. The effect of increased variability in q on the profit per year under quota is slightly negative when the cost of fishing is low but strongly positive when the cost of fishing is high. There is a simple reason for this latter effect. When fishing costs are high, fishing will often be unprofitable. This happens in years when the stock is small due to poor growth conditions in previous years or escapement below target. With variable availability, high availability will sometimes make it worthwhile to exploit a stock which is not at a particularly high level, as high availability raises the catch per unit of effort. There is a greater upside gain than downside loss from variable availability; if low availability and small stock coincide it would just make unprofitable fishing still less profitable but no fishing would take place anyway. Put differently, increased variability of q increases the variability of profits with a fixed lower boundary at zero, so the average profit goes up, much as the variability of company stock increases the value of stock options. This effect also occurs, and is in fact stronger, for fee control when the stock elasticity and the cost of fishing are both high ($c = 0.9$ and $b = 1$).

Finally, Figure 4 illustrates what happens when the market price of fish varies stochastically and the availability of fish is deterministic. The results are rather similar to what happens when the availability of fish varies. This is not surprising; as already explained, variability of the market price has the same effect on escapement as variability in the availability of fish when both are distributed in the same way, as assumed here. In addition, variability of prices affects profits overall.

CONCLUSION

From the above we may conclude that there is no a priori case for preferring quota control over fee control or vice versa except in the case of uncertain stock estimates being the only source of uncertainty. The relative merits of these two types of control depend on economic and environmental parameters such as the cost of fishing, how sensitive the catch per unit of effort is to the stock size (through the stock elasticity), the precision of the stock estimates, and the variability in the availability of fish and the market price of fish. These factors will differ from one fishery to another, so there is no single design that fits all. In Table 1 we summarize how the relative merits of quota control versus fee control depend on the sources and magnitudes of uncertainty and the stock elasticity.

Table 1

How simulated profits from fee versus quota regulation depend on sources of uncertainty. ’Fees’ denotes profit from fees $\geq$ profit from quotas, and ‘quotas’ the reverse.

Source of uncertainty varied from σ = 0.1 to 0.6	Source of low uncertainty fixed at σ = 0.1	Stock exponent $b = 1$	Stock exponent $b = 0.1$	
Stock	-	fees	fees	
Stock	Availability	fees	quotas $\sigma_x < 0.25$	fees $0.25 \leq \sigma_x$
Availability	Stock	fees	quotas $\sigma_q > 0.15$	fees $\sigma_q \leq 0.15$
Price	Stock	fees	quotas $\sigma_p > 0.15$	fees $\sigma_p \leq 0.15$

One question we have not addressed is the design of institutions administering quota controls or fee controls. Obviously much depends on their integrity and how well they are designed to deal with their tasks. This depends on culture and traditions which vary from country to country and which need an entirely different method of analysis than has been employed here.

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ENDNOTES

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[i] We are grateful to Martin Weitzman for useful discussions while we were developing this paper.

[ii] That is, as instruments to achieve a certain target catch or fishing mortality. Fees on fish landings are not unknown for other purposes, such as for financing buy-back schemes or administration of individual vessel quota systems, etc. Such fees are probably minor in relation to what would be needed to limit the total landings to some target.

[iii] It is conceptually possible that the variability of ε could drive the stock to extinction. However, for the variance used in our model (0.04), the probability of this occurring is virtually zero. It does not happen in any of our simulations.

[iv] We have used the lognormal distribution for mathematical convenience, as it ensures that the estimated stock level will never be negative, which in any case will never happen in the real world.

[v] Some authors (e.g., Androkovich and Stollery [1994]) who have used a discrete time model have used the catch function EqX, where X is the stock at the beginning of a period, for the entire period. This is appropriate for a continuous time model but would seem to contradict the logic of a discrete time model where the stock is renewed at regular intervals. Here we would get $Y = X[1 - \exp(-qET)]$ where Y is the total catch over a period of length T and E is the effort applied.

[vi] Again the reason is mathematical convenience; this avoids negative realized values of p and q.

[vii] Individual transferable quotas will not always lead to optimal investment in fleet capacity, as discussed in Hannesson (2000).

[viii] In all simulations we use a = 0.5 and a variance of ε equal to 0.04 (cf. Equation 1).