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Landing Fees Versus Fish Quotas

by

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LANDING FEES VERSUS FISH QUOTAS[1]

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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.

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

Introduction

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) and showed that, in this setting, landing fees are superior to quotas set on the basis of uncertain estimates of the current stock level.

As discussed by Weitzman, there are other types of uncertainties in fisheries which could reverse this conclusion. Managers do not know how fishermen will change their behavior in response to a change in landing fees. Fishermen might possibly react to a higher 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. These uncertainties are, however, not the subject of this paper. 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.

Besides the aforementioned ecological uncertainty, the uncertainties on which this paper will focus 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. 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 fishing and the level to which they will deplete the fish stock. They can be labeled economic uncertainties, in contrast to the ecological uncertainty mentioned above, although the uncertainty about the availability of fish is due to environmental variables such as the weather or ocean currents.

Besides Weitzman's paper (2002), earlier papers by Koenig (1984a, 1984b) and by Androkovich and Stollery (1991, 1994) have addressed the issue of landing fees versus quotas in fisheries. Koenig (1984a) is in 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

The comparison to be made below between landing fees and fish quotas will be based on a management strategy called target escapement; i.e., in every period the stock is fished down to some target level and then left to grow and reproduce. The target stock will be set equal to the optimum stock in a deterministic model. A comparison of truly optimal policies would require a stochastic dynamic programming approach, as optimal policies in deterministic models and their stochastic analogs are not necessarily the same. This we hope to address in a separate paper. In defense of the simple approach taken here it may be said that fisheries policies in the real world are seldom if ever based on economic optimization. In cases when two or more countries share a stock a stock target is arrived at through negotiations between the countries, and there is little indication that economic optimization plays a major role in that process. Even when a stock is controlled by a single country the target stock is determined by rules such as a target fishing mortality or a precautionary level of the spawning stock, neither of which is based on economic optimization. It is therefore certainly a meaningful exercise to study how a given target stock could best be achieved, through fish quotas or through an indirect control through landing fees.

The information structure assumed is as follows. Fishery managers set fish quotas on the basis of imperfect estimates of fish stocks 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.

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

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

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 constant variance.

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. 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 a 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. Hence the target escapement will be equal to the economically optimal escapement in a deterministic model. This is unrealistic if managers are able to forecast the environmental conditions correctly. In that case the optimal target escapement would be affected by the environmental conditions, with fishing being less intense under favorable conditions, 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. We shall use the familiar relationship

(2) $$y = EqX^b$$

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,[2] 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

(3) $$\pi = \int_S^X \left[p - c/qx^b \right] dx$$

[2] 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.

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 subtracting a landing fee τ from the market price (p), but if they cannot predict the market price the price faced 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

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

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

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

We shall assume that q and p are lognormally distributed:

$$(5) \qquad \ln q_t = \varepsilon_{q,t}$$

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

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 landings 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 profits 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 profits as defined in Equation (4) would include 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 as defined here have been absorbed by capital costs. Fee controls would have the advantage vis-á-vis control by a total quota only that the profit would be reduced and there would be less room for increasing the total capacity of the fleet. 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.[3] Strictly speaking, however, this paper does not deal explicitly with the capacity question but only with the question whether fees or quotas will lead to too great a depletion of the fish stock.

Below we report the maximum and minimum profit per year obtained under the two management regimes in each set of simulations (i.e., for each combination of parameters). Looking simply at the average profit per year produced by either fees or quotas would ignore the fact that the results produced by both methods can vary a great deal, depending on whether the development of the stock is "fortunate" or not; a mistake in management at some point can have serious long term consequences under some circumstances. Reporting the "band" within which the average profit per year lies gives some idea of the variability of the profit per period, but obviously the maximum and minimum profit obtained in a single year are outside these bounds and not reported.

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.[4]

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

Figures 1 - 3 show how the profit per period is affected by increasing the uncertainty of the stock estimate, the variance in fish availability, and the market price of fish. As expected, the value of the stock elasticity (b) turns out to be critical, but the cost

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

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

parameter (c) also plays a role for which turns out better, fees or quotas. The thick lines in the figures show the maximum and minimum profit per year under quota control, while the thin lines show the maximum and minimum profit per year obtained with fee control. The profit per year is calculated for each of the 100 simulations and should not be confused with values obtained for individual years, which can be much higher or lower than indicated by the bandwidths in the figures.

Looking first at the effect of increasing uncertainty about stock estimates (Figure 1), we see that for the high cost case (c = 0.9) the effect on the average profit is not great, neither for a "high" nor "low" stock elasticity (b = 1 and b = 0.1); the annual profit is somewhat lower and more variable under quota control than with a fee control. Things are dramatically different when the costs of fishing are low (c = 0.1). With a high stock elasticity (b = 1) the profit per year under quota control falls as the uncertainty about the stock estimate increases, although the bands for fees and quotas partly overlap. With a low stock elasticity the profit per year under quota control becomes much more variable and generally lower than with a fee control, although the band within which the profit per year varies under fee control is contained within the band for quota control.

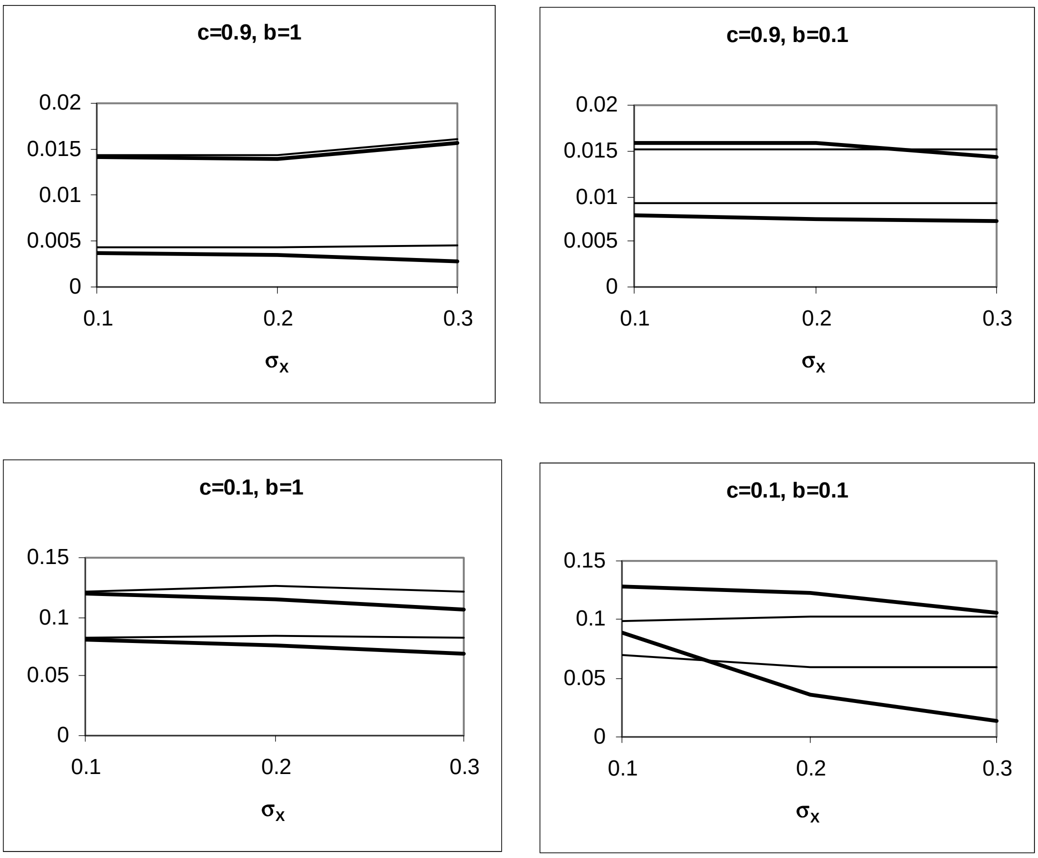

Figure 1

Maximum and minimum 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).

The reason why the profit per year under quota control is little affected by increased uncertainty about stock estimates when the cost of fishing and the stock elasticity are both high 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.

The consequences of increasing the variability of the availability coefficient (σ_q) are illustrated in Figure 2. In the high cost case ($c = 0.9$) we see that increased variability of q is beneficial under quota control, unambiguously raising the profit per year. There is a simple reason for this. In the high cost case, 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 worth while 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.

For a high stock elasticity and a high cost of fishing ($c = 0.9$ and $b = 1$) the effect of greater variability of q is even more positive with a fee control than with quota control, but with a low stock elasticity the effect with fee control turns negative; for $\sigma_q = 0.3$ the profit per year is lower with fee control than under quota control. With a low cost of fishing ($c = 0.1$) and a low stock elasticity ($b = 0.1$) the effect of variable q on profits with fee control is dramatically negative; the profit per year with fee control is way below the profit per year under quota control when σ_q is 0.2 or greater. To see 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*).

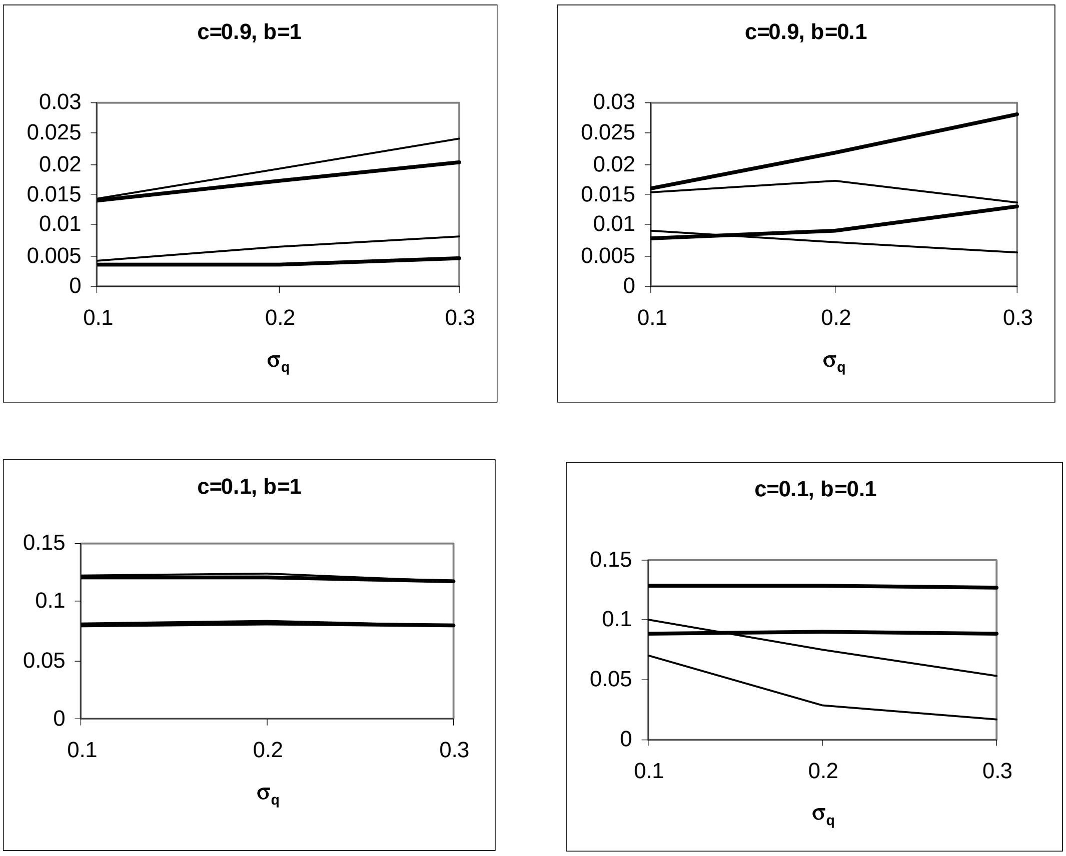

Figure 2

Maximum and minimum 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).

Finally, Figure 3 illustrates what happens when the market price of fish varies stochastically and the availability of fish is deterministic. The results are very 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.

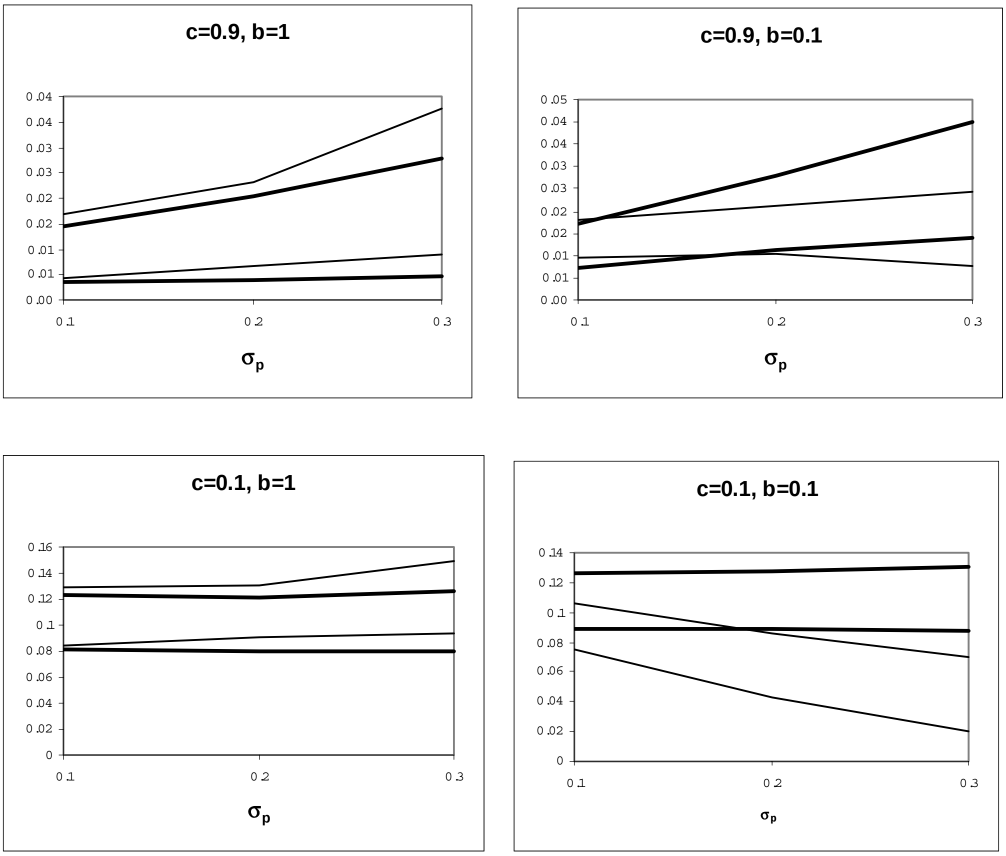

Figure 3

Maximum and minimum 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 ($\sigma_X = 0.1$).

Conclusion

From the above we may conclude that there is no a priori case for preferring quota control over fee control or vice versa; their relative merits depend on economic and environmental parameters such the cost of fishing, how sensitive the catch per unit of effort is to the stock size (the stock elasticity), the precision of stock estimates, and the variability in the availability of fish or the market price of fish. These factors will vary from one fishery to another, so there is no single design that fits all.

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.

References

Androkovich, R.A. and K.R. Stollery (1991): Tax Versus Quota Regulation: A Stochastic Model of the Fishery. *American Journal of Agricultural Economics*, Vol. 73, pp. 300-308.

------ (1994): A Stochastic Dynamic Programming Model of Bycatch Control in Fisheries. *Marine Research Economics*, Vol. 9, pp. 19-30.

Bailey, R.S. and J.H. Steele (1992): North Sea Herring Fluctuations, *in* Glantz (Ed.).

Bjørndal, T. (1987): Production Economics and Optimal Stock Size in a North Atlantic Fishery. *Scandinavian Journal of Economics*, Vol. 89, pp. 145-164.

Costello, C., S. Polasky, and A. Solow (2001): Renewable Resource Management with Environmental Prediction. *Canadian Journal of Economics*, Vol. 34, pp. 196-211.

Glantz, M.H. (Ed., 1992): *Climate Variability, Climate Change, and Fisheries*. Cambridge University Press, Cambridge UK.

Hannesson, R. (2000): A Note on ITQs and Optimal Investment. *Journal of Environmental Economics and Management*, Vol 40, pp. 181 – 188.

Kawasaki, T. (1992): Climate-dependent Fluctuations in the Far Eastern Sardine Population and their Impacts on Fisheries and Society, *in* Glantz (Ed.), pp. 325-354.

Koenig, E.F. (1984a): Controlling Stock Externalities in a Common Property Fishery Subject to Uncertainty. *Journal of Environmental Economics and Management*, Vol. 11, pp. 124-138.

-------- (1984b): Fisheries under Uncertainty: A Dynamic Analysis. *Marine Resource Economics*, Vol. 1, pp. 193 - 208.

Weitzman, M.L. (1974): Prices vs. Quantities. *Review of Economic Studies*, Vol. 41, pp. 477 - 491.

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