Fishery Management with Environmental Prediction[1]

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Introduction

Variations in environmental conditions affect growth of renewable resource stocks. Inter-periodic fluctuation in currents, water temperature, and upwelling in the oceans affect fishery stocks. Variations in temperature and rainfall affect animal and plant populations. The ability to forecast future environmental conditions is improving. For example, El Niño events, which affect salmon and other fish stocks in the Pacific, have been predicted with some success and it is likely that forecast accuracy will increase in the future (Costello et al., 1998, Adams et al., 1995, Barber and Chavez, 1983). By incorporating predictions of future environmental conditions, it may be possible to improve the management of renewable resources.

In this paper, we use a common renewable resource model with stochastic growth to obtain three main results. First, we demonstrate that predictions of poor future environmental conditions lead to lower desired escapement (i.e., low remaining resource stock in place after harvest) and higher current harvest. At first glance, it may seem that predictions of poor environmental conditions should lead to conservative resource management. A prediction of poor conditions means that expected future stock will be depressed, which reduced current harvests can help to mitigate. However, optimal management may require the opposite response to a prediction of poor environmental conditions. Unfavorable future environmental conditions lead to low expected returns to leaving the resource stock in place, making current harvest more attractive. Alternatively, a prediction of favorable future environmental conditions makes leaving the resource in place a good investment, which will tend to decrease current harvest. This result depends on interior solutions (i.e. positive harvest). It is important to note that the optimal response to predictions of future conditions is not the same as the optimal response to shocks to the current resource stock. A shock that lowers current stock should reduce current harvest. Second, we show that under the assumptions of this model, optimal management of a renewable resource requires only a forecast one period in advance. Insofar as forecasting agencies must tradeoff between forecast accuracy and forecast lead-time, this research suggests greater gains can be realized by improving short-term forecast accuracy. The third main result is that provided environmental shocks are bounded within a certain range, access to the resource will never be closed. In this note we first introduce the model and then describe the results, referring the reader to a published version of this model for details (see footnote 1).

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[1] For an unabridged version of this paper, please see our forthcoming paper entitled "Renewable resource management with environmental prediction" in the Candian Journal of Economics.

Model and Assumptions

In this section we present the basic stochastic stock recruitment model and outline the assumptions. Using this model we can show that in the absence of a forecast of environmental shocks, optimal management requires a constant escapement every period (as in Reed, 1979). Let X_t be a random variable describing the size of a population of a renewable natural resource in period t, t=1,2,...,T. The sequence X_t is a Markov process with state transitions $X_{t+1}=f(Z_t,X_t)$ where Z_t is a sequence of positive independently and identically distributed (i.i.d.) random shocks with mean 1 and finite support, [Zlo,Zhi], with 0<Zlo<Zhi<infinity. The function $f(\cdot)$ is a stock recruitment, or growth, function. We assume $f(\cdot)$ is twice differentiable, nonnegative, strictly concave with respect to x, and increasing with respect to both arguments within the relevant region of analysis[2]. After the population is observed in each period, harvest, h_t, is chosen resulting in $y_t=x_t-h_t$ remaining individuals by the end of the period. We refer to y_t as escapement in period t, $y_t \leq x_t$.

Price, P_t is a random variable, though p_t is known in period t. Prices defined by the sequence $\{P_t\}$ are independently and identically distributed over a positive support, with expected future price, p. Although price randomly varies between periods, it is constant within a period and managers are still price takers because their output choice cannot affect price[3]. The assumption that managers are price takers implies that the harvested output is small relative to total market output. Marginal harvesting costs, $c(x_t)$, are assumed to be nonincreasing in stock reflecting increased harvest effort costs with lower populations (thus, within a given season, marginal harvest costs increase as stock declines). Marginal harvest costs and marginal current period profits at the end of the period depend only on the escapement level, y_t, attained, and not on the initial stock, x_t, or harvest level, $h_t=x_t-y_t$, needed to attain that escapement level. No assumptions are required on the concavity or convexity of $c(x_t)$. Holding stock constant, harvest costs are assumed to be linear in harvest. This assumption along with constant price makes the profit function linear in harvest. It is important to have profit linear in harvest for analytic tractability. Estimating the functional form of profit, however, is an empirical matter. There is some evidence that profit is concave in harvest (Dupont, 1990 and Squires, 1988), though it is not possible to solve the model analytically with concave profit.

In general, given escapement in the next period is expected to exceed stock in the next period, the dynamic program can be broken into a series of one period decision problems that involve choosing only that period's escapement. The marginal value of harvest at the escapement level depends only on the escapement level, not the level of harvest in the period. Consequently, the marginal value of harvest at the escapement level is independent of the initial level of stock in the period. In other words, the payoff from choosing a given escapement in period t is independent of the choice of escapement in period t-1. Similarly, the marginal value of increased escapement, which equals the marginal value of harvest at the beginning of the next period, is independent of the escapement level at the end of the next period. The optimal level of escapement in a period is independent of the escapement level in any other period. This fact is a consequence of the general assumptions of this model and it allows us to write the value function explicitly. If either price or marginal harvest cost depends on harvest level in the period, the dynamic program cannot be broken into a series of one period decision problems. Choosing optimal escapement levels with an objective function explicitly depending on harvest is considerably more complex.

Main Results and Conclusions

As the ability to predict future environmental conditions improves, potential gains can be made from incorporating these predictions in renewable resource management. In the case where there will be positive harvest in the next period (an interior solution) and where profit is linear in harvest, a shift toward improved environmental conditions, which increases growth of the stock, increases optimal current escapement (decreases current harvest). On the other hand, a shift toward worse environmental conditions decreases optimal current escapement (increases current harvest).

The result that the prediction of the quality of future environmental conditions is inversely related to optimal current harvest may come as a surprise to some. When there will be positive harvest in the next period and profit is linear in harvest, extending the forecast time horizon beyond one period has no value. In general, positive harvest combined with a linear profit function in harvest cuts the link between optimal escapement in one period and optimal escapement in the next period. With either the possibility of zero harvest or non-linear profit there is

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[2] This allows the possibility of depensatory growth where extinction is a stable steady state. So long as managers never push the stock below the critical level for convex growth to occur, the relevant region is concave.

[3] This allows slightly more generality than an assumption of fixed price at a relatively low computational cost, as all decisions made by the manager in the forthcoming analysis rely only on p.

value, though it is likely to be small, to learning about conditions one year in advance.

The feeling that a prediction of future adverse environmental conditions should lead to conservative resource management may spring from the concern that low stock levels increase the likelihood of extinction. However, in this model with concave growth, extinction only occurs if harvest equals stock in some period. In a model with depensation, where growth is not sufficient for replacement at low levels of stock, there is heightened probability of stock extinction with low escapement. Clarke and Reed (1994) imply that if extinction risk increases with decreasing stock, management is more conservative than management in a risk-free world. In this case, a prediction of adverse conditions may reduce optimal harvest.

We also examine the effect of extending the time horizon of the forecast. When there will be positive harvest in the next period, extending the time horizon beyond one period has no value. In general, positive harvest in a period cuts the link between optimal escapement in one period and optimal escapement in the next period. Only when there is the possibility of zero harvest in the following period is there value to learning about conditions beyond one year in advance.

The results of this model rely on the assumption that marginal profit depends only on stock level and not on the level of harvest. Either downward-sloping demand or increasing marginal cost of harvest would cause the returns function to be concave in current harvest. With concave returns, there is a loss from having highly variable harvest from period to period. Therefore, not all of the adjustment to shocks should occur in the period after the shock. Rather, there is a benefit to smoothing harvest across periods. Further, concave returns would lessen the inverse relationship between current harvest and prediction of future environmental conditions. Under harvest smoothing, knowing that in the future there will likely be lots of stock would tend to increase current harvest. If this effect is strong enough it is possible that it might reverse the results found in this paper. The fact that improved environmental conditions yields greater physical returns of stock and larger stock lowers marginal harvest cost, however, make it likely that forecasts of improved environmental conditions should yield higher optimal escapement, i.e., lower current harvest. In simulation results from a model with profit concave in current harvest, Costello et al. (1998) found a negative relationship between current harvest and a prediction of future environmental conditions. We leave a formal treatment of optimal harvest with predictions of future environmental conditions in a non-linear model for further study.

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