Green Accounting for a Commercial Fishery

Robert D. Cairns
Department of Economics
McGill University

Abstract

The theory of extensions to the national accounts is expressed in models in which wealth is being explicitly maximized. For the fishery, the central issue is such valuation when the policy being followed is inefficient. We begin the task of making such valuations for commercial products of a fishery. Capacity is limited by investment in fishing boats. Therefore, depreciation of the boats has to be evaluated as well as depletion of the fish stock. Depletion of a non-optimal fishery can be evaluated, and is always greater than depletion of an optimal fishery. Statistical requirements are found and examples are given on how to apply them.

KEY WORDS green accounting, fishery, non-optimality, capacity, depletion

1. INTRODUCTION

The fishery is one of the most important natural resources, economically and ecologically. It is of clear importance to individual nations and to the world community to have a quantitative index of the depletion of this resource for policy making. This is especially true because natural fisheries are overexploited, with overinvestment, excess labor and overcatching.

The aims of green (or environmental) accounting are to recognize the economic contributions of natural resources to society and to record the depletion or appreciation of those resources. Much of the literature is based on models in which aggregate welfare is maximized. Hence, it is not directly applicable to fisheries which are subject to open access and consequently overexploited. Moreover, frequently the models lose sight of the role of produced capital by stressing that of environmental capital. In this paper we begin the task of making valuations for commercial products of a fishery, abstracting from the vital yet difficult determination of the value of the ecological functions of the fish being harvested. Capital and capacity constraints are an explicit focus of our investigation. Therefore, the analysis is disaggregated. If running down stocks is comparable to pollution, it is of interest to track the realizations of individual fishers.

A resource's value is low if it is poorly managed, just as the shares of a traded company with great potential may have a low value if the company is poorly managed: The benefits (earnings, dividends) are low, and for this reason the company's shareholders have a lower level of wealth. Comparison with what could be attained if optimal policies were in place depends on an evaluation of policy in place. This is exactly the approach of the national accounts to the evaluation of economic performance.

2. THE FISHERY

Because the national accounts evaluate the results from individual enterprises and aggregate them, in this paper we consider the equilibrium of an independent fisher. As suggested in an early model by Clark, Clarke and Munroe (1979), participation in the fishery involves use of a boat with a given capacity, which we shall call K, and exertion of an effort $E \leq K$.

Modeling the economics of a fishery can be mathematically difficult. Confidence in the forms (let alone the parameters) of the harvest and growth functions is invariably low. Fortunately, our results can be obtained using a fairly general model. We consider here the effects of the decisions of an individual fisher in a situation which could be one of (a) an open-access fishery, (b) a Nash equilibrium among a fixed number of fishers, or (c) a regulated fishery. Given a stock of fish, S, let the fisher's harvest function be $q(S,E)$. Let the current cost of fishing, i.e. the value of the fisher's labor and any other current costs such as bait, be $C(E,K)$. For simplicity, and following much of the literature on the fishery, we assume that both functions, $q(S,E)$ and $C(E,K)$, are linear in effort. Common assumptions are that $q(S,E) = S^{\sigma}E$ and that $C(E,K) = cE$. As Clark *et al.* show, linearity implies a bang-bang solution: $E = K$ or else $E = 0$. In a suboptimal fishery, the same type of bang-bang policy can be assumed to hold for price-taking, profit-maximizing fishers. Let the natural rate of increase of the stock be $g(S)$. The net rate of change of the stock, $\dot{S}$, is this natural rate of growth minus the aggregate harvest.

Clark *et al.* allow for the possibility of (physical) deterioration of capacity. Suppose that a boat with capacity K_0 is purchased at price P at time $t = 0$. At that point, a net investment of PK_0 is recorded in the accounts. Deterioration can occur as a continual diminution of capacity at some rate $\delta(t) = \dot{\gamma}(t)$, so that capacity at time t is $K_0 \exp\left[-\int_0^t \delta(s)\, ds\right] = K_0 e^{-\gamma(t)}$, or through destruction of the fishing boat at some hazard rate $h(t) = \dot{\alpha}(t)$, so that the probability of survival to time t is $\exp\left[-\int_0^t h(s)\, ds\right] = e^{-\alpha(t)}$. We distinguish between deterioration and depreciation, which is a decline in (financial) value.

Following the practice of the national accounts, we evaluate at market prices where possible. Let the market price of fish be $p(t)$. The probability of a fisher's remaining in the industry until time $t > 0$ and gaining the net revenue,

$\pi = pq - C$, at time t is $e^{-\alpha(t)}$. At time t, the expected present value, evaluated at rate r, of participation in the fishery with a fully utilized boat is

$$\begin{aligned} V_t &= \int_t^{\infty} e^{-[\alpha(s)-\alpha(t)]}\{p(s)\, q\left(S_t, K_0 e^{-\gamma(s)}\right) \\ &\quad -C\left(K_0 e^{-\gamma(s)}, K_0 e^{-\gamma(s)}\right)\}e^{-r(s-t)}\, ds \\ &= \int_t^{\infty} \pi_s \exp\{rt + \alpha(t) - rs - \alpha(s)\}\, ds. \end{aligned}$$

Participation involves the exploitation of the boat as well as the stock of fish, and both of these capital and capital-like stocks are "used up" in the fishery and need to be depreciated out of the monetary gains from fishing.

Conditional on the boat's survival until time t, depreciation of the value of participation is negative the rate of change in value:

$$D_t = -\dot{V}_t = \pi_t - [r + \delta(t)]\, V_t,$$

so that, for a going concern,

$$(r + \delta)\, V = \pi + \dot{V} = \pi - D.$$

This is a familiar formula for the fisher's contribution to net national product: the return on the value of participation is equal to current net revenues minus depreciation. The return includes an appreciation of value, at rate $\delta(t)$, that arises from survival in the industry, and can be viewed as compensation for the hazard of ruin. Also, the formula apples to what may be a suboptimal fishery. It does not involve the Hamiltonian from an optimal-control problem. Rather, it relies upon the first fundamental theorem of calculus.

Total expected depreciation over all fishers in the industry, indexed by i, is $\sum \pi_i - \sum rV_i$. This total is strictly less than the net revenues of the industry, i.e. aggregate variable profit minus aggregate depreciation of boats.

If a boat is lost at time t,* the depreciation is V. This feature is another adjustment to the individual fisher's accounts. The undepreciated value of a lost boat would be written off in normal accounting, but the value V is the value of participation, and is greater than that of the boat.

In an optimally managed fishery, let W_t be the optimal value and suppose that there are $N(t)$ identical fishers. The goal is to find

$$W_t = \max \int_t^{\infty} N(s)\, \pi_s \exp\{-[rs + \alpha(s) - rt - \alpha(t)]\}\, ds.$$

By the first fundamental theorem of calculus,

$$\dot{W}_t = (r + \delta)\, W - N\hat{\pi}, \text{ or}$$

$$(r + \delta)\, W_t = N\hat{\pi} + \dot{W}_t,$$

where a circumflex denotes the optimal.

*Strictly speaking, ruin occurs on an interval of length dt at t, with probability $\delta(t)\, dt$.

Proposition 1 *Total depreciation for a going concern is equal to the sum of (a) depreciation of capital (deterioration evaluated at a shadow price), (b) depletion (net degradation of the fish stock evaluated at a shadow price), and (c) the change in the value of participation due to the passage of time alone. If the problem is autonomous, then total depreciation is equal to the sum of the depreciation of capital and depletion of the fish stock.*

Proof. If $\delta(t)$ and $h(t)$ are not constant, the optimal value function, W, is non-autonomous, a function of t as well as S and K. By direct differentiation,

$$\dot{W} = (\partial W/\partial S)\, \dot{S} + (\partial W/\partial K)\, \dot{K} + \partial W/\partial t.$$

In a suboptimal program, it is reasonable to write the expected value as depending on the stocks, $V(S_t, K_t, t)$. If the function V is differentiable, then a similar equation holds:

$$D = -\dot{V} = -\left[\dot{S}\,(\partial V/\partial S) + \dot{K}\,(\partial v/\partial K) + \partial W/\partial t\right].$$

In an autonomous problem, $\partial V/\partial t = 0$. ■

It seems sensible that total depreciation is greater at a suboptimal fishery than an optimal fishery. But it could be that the value of the program at a suboptimal fishery is diminished by so much that its depreciation is less than for an optimal fishery. We verify the intuition of the initial statement in the following.

Proposition 2 *Given the same stocks at time t, total depreciation and depletion are greater in a suboptimal than an optimal program.*

The Lagrangean for the optimization problem is

$$L = N\pi + \lambda(g - Nq) + vN(K - E) + wNE$$

and the first-order condition is

$$N[\partial\pi/\partial E - \lambda\partial q/\partial E + w - vfs] = \partial L/\partial E = 0, \text{ or}$$

$$\partial\pi/\partial E = v - w + \lambda\partial q/\partial E.$$

(a) Suppose that $\hat{E} > 0$. Then $w = 0$ and $\partial\pi/\partial E > 0$. Since $E > \hat{E}$ (exploitation is greater in the suboptimal program),

$$pq(S, E) - C(E, K) > pq\left(S, \hat{E}\right) - C\left(\hat{E}, K\right).$$

Because W is optimal and V is suboptimal, $W/N > V$. Also,

$$\begin{aligned} (r + \delta)\, W(S_t, K)/N &= pq\left(S_t, \hat{E}\right) - C\left(\hat{E}, K\right) + \dot{W}/N \\ &< pq(S, E) - C(E, K) + \dot{W}/N \\ &= (r + \delta)\, V(S_t, K) - \dot{V} + \dot{W}/N. \end{aligned}$$

Therefore,

$$\left(-\dot{V}\right) - \left(-\dot{W}/N\right) = (r + \delta)\,[W(S_t, K)/N - V(S_t, K)] > 0.$$

(b) Suppose that $\hat{E} = 0$. Then $\pi = 0$. But $pq(S,E) - C(E,K) \geq 0$. A similar argument shows that $\left(-\dot{V}\right) \geq \left(-\dot{W}/N\right)$. ■

As is suggested by our discussion, total values (for the fishery) of the contributions to net national product and of depreciation are the sums over values for the individual fishers. This corresponds to the practice of the national accounts in summing the values added at individual enterprises.

The shadow values for evaluating depreciation of capital and depletion, $\partial V/\partial K$ and $\partial V/\partial S$, are, from a strictly theoretical point of view, required for decomposing depreciation of the value of participation, D, into its components, $\dot{K}\partial V/\partial K$, $\dot{S}\partial V/\partial S$ and $\partial V/\partial t$.

Estimating shadow values is difficult. In practice, the national accountant must provide as much information as possible about performance of the fishery using available data. If the problem is non-autonomous, it seems natural to include $\partial V/\partial t$ in the measure of the depreciation of capital. Also, in reality, the theoretic value function is an *expected* value, and what is needed is an accounting of *realized* values. Accountants through the ages have discovered that it is adequate for making decisions to use a predetermined formula for the depreciation of capital, so long as total (undiscounted) depreciation is equal to the original value: $\int_0^\infty D_t\,dt = V\,|_0$. This formula holds for other schedules than $\dot{V}_t$; a common schedule is straight-line over an estimated lifetime, T: if P is the price of capital goods, depreciation is PK_0/T for $t < T$ and zero thereafter. Given that such predetermined formulas are used for depreciation of capital in the accounts, the expression for depletion by an individual fisher can be adapted, to be $\Delta_t = D_t - PK_0/T$ for $t < T$ in this example. The long-run effect of such an adaptation should not be great, as the undiscounted total depletion is not affected.

But depreciation of capital in the fishery also includes the write-off of lost boats; at time $t < T$, that write-off is $\Omega = PK_0/(T-t)$. The depletion of the fishery is, then, $\sum_{i\in G}\Delta_i - \sum_{i\in L}\Omega_i$, where G is the set of going concerns and L is the set of boats lost at time t. *The total depletion imputed to individual going concerns overstates the true depletion of the fishery by the realized disinvestment in lost boats.* Extended or satellite accounts need to recognize this feature explicitly, as depreciation of lost boats will not be imputed to going concerns.

Finding more specific results requires making assumptions about the various functions in order to evaluate $D_t = -\dot{V}_t$. Consider the following examples.

Example 1 Exponential decline of the fishery. *Suppose that $S = S_0 e^{-bt}$. that $C(E,K) = cE$, that $q(S,E) = ES^\sigma$, and that $p(t)$ is constant. The equilibrium is bang-bang, with $E = K$ if $S > (c/p)^{1/\sigma}$ and $E = 0$ if $S < (c/p)^{1/\sigma}$.* Let $\alpha(t) = \xi t$ and $\gamma(t) = \zeta t$. Since decline of the stock implies that exploitation is positive, and hence that $E = K$,*

$$V_t = \frac{pq_t}{r+\xi+\zeta+\sigma b} - \frac{cK}{r+\xi+\zeta} < \frac{pq-C}{r+\xi+\zeta}.$$

Present value is strictly less than the current net cash flow expressed as a perpetuity at rate $r+\xi+\zeta$ (the interest rate plus the rate of deterioration of capital), because revenues are discounted at an effective rate $r+\xi+\zeta+\sigma b$. If, for example, (i) $r = \xi = \zeta = \sigma b = 0.10$,

$$V = 5\pi/2 - 5C/6.$$

The value of participation in the fishery is less than two and a half times the current net revenue.

The fact that value is low means that depreciation and depletion are low. Depreciation of the value of participation is

$$D = -\dot{V} = \pi - (r+\xi)\,V = \frac{\zeta+\sigma b}{r+\xi+\zeta+\sigma b}pq - \frac{\zeta}{r+\xi+\zeta}C.$$

The fisher's attributed depletion of the stock of fish is total depreciation, D, minus the depreciation of capital. Suppose that capital is depreciated according to straight-line depreciation over T years at rate PK_0/T. Then depletion is

$$\Delta = D - PK_0/T = \frac{\zeta+\sigma b}{r+\xi+\zeta+\sigma b}pq - \frac{\zeta}{r+\xi+\zeta}C - PK_0/T.$$

The contribution of the fisher to net national product is $pq - C - D$. In this example, this is equal to $pq/2 - C/3$. Variable cost C may be included elsewhere as being paid to the fisher and the supplier of bait.

Example 2 Moratorium. *Consider now the effect of a moratorium lasting from time τ_1 until time τ_2. Let rates of deterioration be constant. On the time interval (τ_1,τ_2), let boats be lost at rate ζ_m, a rate which may or may not be equal to $\zeta = \delta(t)$. The capital stock at time τ_2 is $K' = K_{\tau_1}e^{-\zeta_m(\tau_2-\tau_1)}$. At time $t \in (\tau_1,\tau_2)$, the value of participation is*

$$V_t = \int_{\tau_2}^{\infty} \left[pq(S,K') - C(K',K')\right] e^{-(r+\zeta)(s-t)}ds.$$

In this case, there is an appreciation *of the value of participation (of this fisher's share of the fishery):*

$$D = -\dot{V} = -(r+\zeta)\,V_t.$$

*The assumption of exponential decline is for tractability only. It can apply only when production is positive, and hence at capacity in the bang-bang solution. Suppose that there are N identical fishers. The implication is that $-bS = \dot{S} = g(S) - NKS^\sigma$. Then, $g(S) = S\left(NKS^{\sigma-1} - b\right)$. If $\sigma < 1$, this function is of the form of a simple growth function. But it is a special case because it involves parameters of the production process.

The reasons are (1) that the stock is growing and (2) that the time τ_2 when the moratorium is to be lifted is closer.

If, as before, the value of the optimal program from time τ_2 is W, then $-\hat{D} = (r+\zeta) W_t > (r+\zeta) V_t = -D$. Formally, we retain the result for the comparison of the optimal and actual programs. Appreciation of the value of the optimal program is greater than that of the suboptimal equilibrium, which involves (a) possibly a moratorium of non-optimal length and (b) non-optimal exploitation after the moratorium is lifted.

Example 3 A sustained fishery. *A fishery can be sustained by price (tax) or quantity (quota, including transferable quota) instruments. Suppose that an effective policy is in place.*

In an optimal sustained fishery (in the steady state, with $\dot{S} = 0$), there must be gross investment of $\hat{I} = [\delta(t) + h(t)]\hat{K}$ to offset deterioration. The fishery is run on a unitized basis, and so it is easier to discuss the aggregate equilibrium.. In this case, $W = N\left(p\hat{q}\left(\hat{S},\hat{K}\right) - \hat{C} - P[\delta(t) + h(t)]\hat{K}\right)/r$, a constant, and total depreciation, $\left(-\dot{W}\right)$, is nil. The contribution to NNP is rW, total revenues net of all costs. This includes the contribution of the undepreciated value of capital. In practice, the value of the contribution of the fishery will depend on the schedule of depreciation chosen for the boats of the industry.

Similar conditions hold in non-optimal, sustained fishery.

3. PRACTICAL CONSIDERATIONS

In more realistic situations the estimation of depletion is more complicated.

If the harvest function is $q(S,E) = E^{\varepsilon}S^{\sigma}, \varepsilon \neq 1$, the program does not have a bang-bang solution and effort can be strictly between nil and capacity. This is of practical importance, because overcapacity $(0 < E < K)$ for individual fishers is frequently observed. If capital is redundant throughout the program, then its shadow value is nil but accounting depreciation will not be. If $\varepsilon \neq 1$, then effort does not enter linearly, and it is not possible to use aggregate effort as an argument in an aggregate model. One is even more obliged to use a micro approach.

If a fisher's harvest is regulated by a quotum Q, transferable or not, a new condition, $E \leq Q$, applies as well as $E \leq K$. This is true even if $\alpha \neq 1$ in the harvest function, $q(S,E) = E^{\alpha}S^{\sigma}$.

If the equilibrium is a Nash equilibrium among $N(t)$ fishers, each will recognize a shadow value, $\lambda(t)$, of the stock, and $(p(t) - \lambda(t))$ replaces $p(t)$ in the conditions relating to when $E = K$ or $E = 0$.

If the rate of decline of the stock is not exponential, the present value cannot be so easily computed. Trade-offs between theoretical accuracy and practicality are necessary. Practical considerations include ease of gathering statistics and the objectivity of statistics, including imputations. For example, the decline of a fishery may be close to exponential at some rate b over a number of years. In this case, the formulas given in Example 1 are reasonably accurate.

4. CONCLUSION

Our examples suggest that the statistical requirements for valuing the fishery include (on an individual basis or an aggregate basis) are:

1. current revenues from fishing, pq,
2. current variable costs of fishing, C,
3. the undepreciated (remaining) value of the capital stock.

Furthermore, there is need to capture the main characteristics of the growth and production functions to estimate depletion and hence the net contribution of the fishery. In our example of the exponentially declining fishery, which is a simplification of reality, we require

1. the rate of decline in stocks of the fishery, b, and
2. the elasticity of catch to the stock, σ.

The formulas given in the text measure the theoretical depreciation of the combination of resource and capital in place, rather than what is really desired, the realized depreciation. For purposes of green accounting, exact estimates will be elusive. The effects of many compromises will wash out over time, however. Recall that the depreciation of capital is estimated using a simple formula rather than by an attempt to compute the change in the present value of its productivity. By retaining the estimate of capital depreciation, the accountant can attribute depletion to the resource as a residual.

The important lesson is that the formulas are conceptually simple and can be used to approximate depletion even if a fishery is exploited suboptimally. Research should focus on reasonable approximations of depletion in different circumstances.

REFERENCES

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