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Fishery Economics: An Introduction and Review

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FISHERY ECONOMICS: AN INTRODUCTION AND REVIEW

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INTRODUCTION

This paper introduces the reader to the study of fishery economics. Four questions are addressed. How should a fish stock be utilized by society? Is the optimal stock size that which produces maximum sustainable yield? Next we examine the properties of a free access fishery, where there are no restrictions on entry, determine whether an equilibrium can exist in such a fishery, and if so, attempt to describe its characteristics. Finally, what sorts of regulations, quotas, and taxes can a fishery manager use to achieve socially optimal regulation? These questions are not fully answered here; the intent is rather to explain the factors economists feel must be considered if the questions are to be answered correctly.

The study of the fishery begins with the realization that fish are just one of society's many scarce resources. Resources are factors of production providing indirect benefits to society, through their contribution to the production of desired goods and services. They are not consumed directly. Economics is concerned with the allocation of these scarce resources. Scarcity generates the basic economic problem of choice. If we cannot have everything we want, we have to choose one alternative and another has to be sacrificed. Two questions concerning resource utilization arise. *First,* what proportion of society's resources should be allocated to the production of consumer goods and services today, and what proportion should be saved (either in their natural form or in the form of man-made capital) to be used in future periods? *Second,* society must decide how to utilize the resources allocated to this period. As soon as society decides that product x will be produced, fewer resources are available to produce product y.

The problem of scarcity and choice is often best described in terms of costs. Cost means the opportunity cost, i.e. the quantity of

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the next best opportunity that was sacrificed. The opportunity cost of producing one unit of product x is the amount of product y sacrificed because we chose to produce one more unit of x; where y is the product we would have liked to have produced, if we had not produced that last unit of x. The monetary cost of a good should be thought of as a measure of the alternative goods and services sacrificed.

One of the costs fundamental to our analysis of the fishery is the interest rate. The interest rate is the price that relates the future to the present. It expresses how consumption today substitutes for consumption in the future. For example, a dollar deposited in a bank account today will earn interest at some rate (r). The opportunity cost of spending \$1 today is therefore (1 + r) dollars a year from today. Alternatively, the opportunity cost of spending \$1 t years from now in terms of dollars today is $1/(1+r)^t$ dollars. Generally we are not indifferent between present and future consumption. For example, most people would have a preference for one of the following two alternatives; a bundle of goods received today, or the same bundle received next year. The magnitude of that preference can be represented with an interest rate.

The benefits from a fishery are realized over time, but must be evaluated in terms of their present value. The present value of this stream of benefits can be determined using the interest rate. This can be seen by examining the present value of any future stream of payments. For example, how much will you pay someone today to deliver to you \$1000 now, \$1000 a year from today, and \$1000 two years from today? Evaluating each term separately, one can see that the present value (PV) of the three payments is $\$1000 + \$1000/(1+r) + \$1000/(1+r)^2$, i.e. $\sum_{t=0}^{T} y_t/(1+r)^t$, where t = 0,1, . . . ,N. The present value of any future stream of discrete payments can be represented by this formula. We will, however, utilize the PV formula for a continuous stream of payments which is $PV = \int_0^{t_1} e^{-rt} y_t \, dt$.[1] This latter formula is chosen because treating payments as a continuous, rather than discrete, stream will simplify the analysis of the fishery.

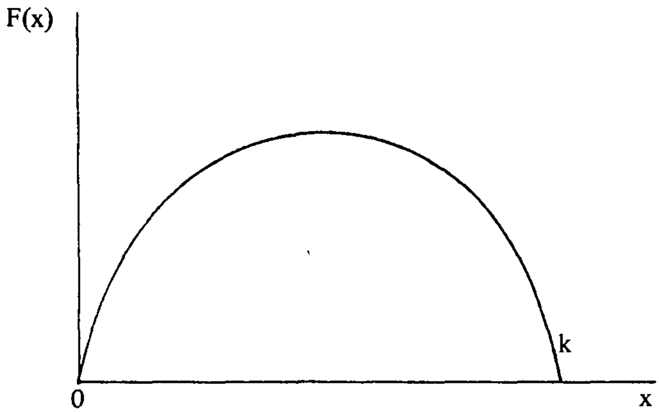
1. In the limit as the number of discrete time periods, T, → ∞; and the length of each time period, Δ, → 0 (given ΔT = t);

$$\sum_{t=0}^{T} y_t/(1+r\Delta)^t \rightarrow \int_0^{t_1} e^{-rt} y_t \, dt \quad .$$

We are now ready to consider a fish stock.[2] The fish are part of society's capital stock and society must decide how they are to be utilized. Assume that at any point in time t the stock can be completely described by x_t, where x_t is the biomass at time t. Age distribution and other characteristics of the stock are assumed unimportant. Let us assume that the fish stock grows at the rate F(x), where $F(x) = \frac{\partial x}{\partial t}$, $F(x) > 0$ for $0 < x < k$, $F(0) = F(k) = 0$, $F''(x) < 0$, and $\lim t \to \infty\ x_t \to k$ in the absence of fishing. The carrying capacity of the environment in which the stock lives (k) is determined by climate (water temperature, currents, etc.), number(s) and types of natural predators, and available food supply. The stock grows at a positive rate for stock sizes greater than zero, but less than k. If there is no fishing, the biological equilibrium (k) is approached as time goes to infinity (Figure 1).

FIGURE 1

The Population Dynamics of this Fish Stock



Probably no existing fish stock can be described so simply, but the adoption of this biological model makes it simpler to elucidate the economic approach to the problem of determining the optimal stock. The intent here is not to determine the optimal amount of an actual

2. The simple fishery model considered is taken from C. CLARK, THE OPTIMAL MANAGEMENT OF RENEWABLE RESOURCES (1976) and Clark & Munro, *The Economics of Fishing and Modern Capital Theory: A Simplified Approach,* 2 J. ENVT'L ECON. & MANAGEMENT 92 (1975).

fish stock, but rather to describe the theoretical economic technique that must be used if such a problem is to be correctly addressed.

The fish stock is a natural resource which can be combined with other resources, fishing boats, the labor of fishermen, etc., to produce a good (food) that people want.[3] It is important to remember that a fish stock is just one of society's many resources. Fish are scarce, hence, there is an opportunity cost to use the resource. Today's consumption of fish often requires a sacrifice of fish in the future. We therefore have to decide how to use the resource over time. Do we use more of it today, or less, i.e. do we save it (invest in the stock) by letting the stock grow so there is more in the future, or do we deplete it (disinvest)? Economists are concerned with this question: the problem of choice over time, i.e. the determination of the optimal harvest rate for the fish. What does the optimal rate mean? Very simply, the utilization (the harvesting) of the resource which brings the greatest enjoyment (satisfaction) to society over time. Since resources are scarce, it is important that they are used so as to attain their maximum potential contribution to society's welfare. Society, it should be remembered, consists not only of people living today, but also encompasses all future generations. The next section describes this optimal rate for exploiting the fish stock, by examining the harvesting rule that will bring the greatest amount of welfare to society.

THE OBJECTIVE OF FISHERY MANAGEMENT

This section discusses the proper goal for the manager of the fish stock, i.e. what he should try to accomplish if he is in charge of the stock's rate of exploitation. The manager's problem has to be completely specified. The fish stock and its dynamic properties were defined in the first section. Now the production function for fishing must be examined.[4] Assume that the production function for fishing has only two inputs. These are the fish stock (x) and an aggregate called fishing effort (E). Fishing effort is an index of a number of fishing inputs. For example, it might be some index of the fishermen's time, fishing equipment, processing plants, etc. Assume that the indexing formula is known. One therefore can take the amounts of all the inputs used in fishing (i.e. two boats, six fishermen, and

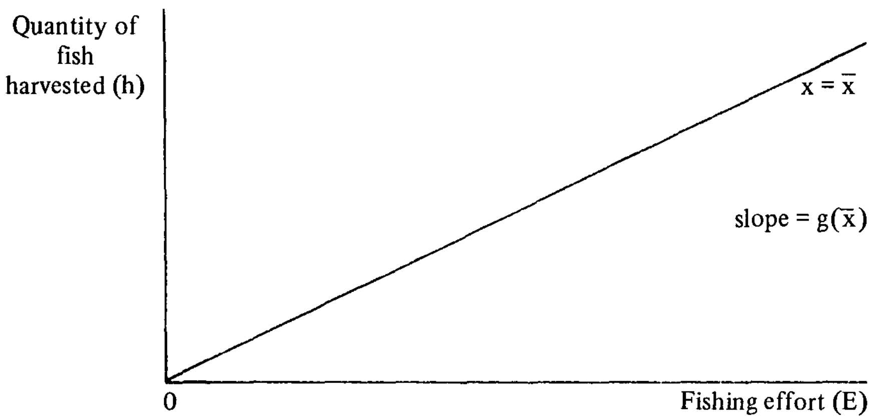
3. Fish products are often unrecognizable as such when they reach the table. Fish products include, for example, poultry which has been fed fish meal.

4. A production function is a mathemtical relationship that describes the technological and/or biological relationship between a group of inputs (natural resources, reproducible capital, labor, etc.) and some particular output, or group of outputs.

one processing plant) and through the indexing formula convert them into units of E. In practice, fishing effort is difficult to measure. The consequences of this for regulatory purposes will be discussed later, but for now assume that there are only two easily measured inputs, fishing effort and the stock size. The output, or harvest rate, is the amount of fish caught and processed in a given period, i.e. the quantity of fish ready for consumption in that period. The harvest rate (h) at some time t, is some function (q) of x and E ($h = q(x,E)$). For different combinations of x and E, the function describes how much h is produced. Assume that h has the following simple form: $h = g(x)E$, where g(x) is nondecreasing in x. This production function describes for the manager of the fish stock the technology at his disposal, i.e. how he can combine different amounts of x and E to catch a certain amount of fish (h). This is a restrictive production function; E enters the function in a linear fashion. Therefore the rate of change in the harvest rate with respect to a change in the level of effort $\left(\frac{\partial h}{\partial E}\right)$ is independent of the level of effort. Two more restrictions on the technology must be imposed. (1) A negative harvest rate is assumed to be impossible. (2) Assume that h cannot be greater than some maximum value which we will refer to as h_{max}, where h_{max} is some function of the stock size at time t and the time period itself $h_{max}(x_t,t)$. At any particular point in time $0 \leq h \leq h_{max}$. The reasons for adopting such a simple production function will become evident (Figure 2).

FIGURE 2

The Harvesting Function



Next, assume that the price (w), or the wage rate, for fishing effort (E) is constant.[5] The fishery manager has no control over w; he treats it as a given. This assumption can be justified if one assumes that the price of effort is determined competitively in a large market where the manager is such a small agent that regardless of how much effort he buys, he has no influence on w. In this case, w is the opportunity cost to society of using one more unit of effort to harvest fish.[6] It measures what society is giving up, what is being sacrificed, every time one more unit of this particular resource (E) is allocated to the production of catching fish. If society had not used this last unit of effort to catch fish, it could have been used to produce some other goods or services. These alternative goods would have had some value (w) to society. Therefore, the cost per fish harvested (c(x)), given that $h = g(x)E$, is

$$c(x) = w/g(x)$$

where c(x) is the opportunity cost of harvesting a fish. It is a measure of how much society sacrifices, in terms of other goods, every time it uses its resources to harvest one more fish in the current period.

Next assume that the price of fish (p) is given from the point of view of the fishery manager. Again, one can assume that it is determined in a large market, where the fish supply from our stock is such a small proportion of the total supply, that no matter how many fish we deliver, the price of fish will not be affected. Prices, in general, are measures of relative value. The price (p) is some measure of the relative benefits society gets from fish compared to other products. For example, if the price of fish is $10 per kilo, and the price of beer is $20 per kilo, then, under certain conditions one could infer that society values a kilo of beer twice as much as a kilo of fish. Prices indicate nothing about the absolute amount of satisfaction produced by the consumption of different goods, but this is of no importance.

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5. One can either assume that: (1) the fishery manager purchases, at parametric prices, the different components of fishing effort, then combines them to produce units of E, in such a way that the cost of E is minimized, or (2) one can abstract from this cost minimization problem and assume that the manager buys units of E directly. In either case, w, the minimum cost of a unit of E, is parametric to the manager. For simplicity of exposition we shall temporarily assume that units of E are purchased intact.

6. In a competitive system each unit of E is paid the value of its marginal product ($w = p_{fish} \cdot \partial h/\partial E$). Competitive equilibrium requires that all E (independent of its use) is paid the same w (otherwise some units of E would be in the process of moving to more productive uses). Therefore, in equilibrium, $w_{fishing} = p_{fish} \cdot \partial h/\partial E = w_{nonfishing}$ = the value of E's marginal product in the production of other goods = the opportunity cost of using one more unit of E to harvest fish.

We only need to compare the amount of enjoyment derived from consuming one good with the amount derived from consuming some other good. However, there are potential reasons why prices might not reflect actual relative values of different goods to society. Market failures (due to externalities, public goods, decreasing cost industries, etc.) and an inequitable distribution of income both distort the ability of prices to reflect relative values. One can either temporarily assume away such distortions or assume that the government determines p (the relative value of fish to society).

Next, the social rate of discount (δ) must be specified. It is that interest rate with which society evaluates benefits and costs that accrue in future periods. Society decides on some social rate of discount, an interest rate, which is then used to determine the present value of future benefits and costs. So δ relates benefits and costs accruing to different generations. The determination of δ is an extremely difficult and important problem. In the interest of brevity assume that its value is determined by the government, which then informs the fishery manager of its decision. The government may not explicitly decide that δ is .05 or .10, but its policies and expenditures affecting current and future consumption reflect some implicit social rate of discount. We assume that the government is explicit about its choice of δ. For our purposes it is important only that the fishery manager knows how to compare benefits that accrue to future generations with benefits that accrue to the present generation.

It is further assumed that δ falls between infinity and 0; negative discounts rates are disallowed. A negative discount rate implies that the future is preferred to the present, while a discount rate of infinity implies that no one cares at all about the future. If $\delta = 0$ the current value of any future consumption is zero. If infinity were one's personal rate of discount, one would not save. The only reason to save is to be able to consume more tomorrow. At the other extreme, a zero social rate of discount implies that society is indifferent to when benefits (or costs) occur. A benefit of \$1000 accruing to society 10,000 years from now is just as important today as a benefit of \$1000 received today. Therefore the welfare of all generations is weighted equally. The implications of a zero discount rate are quite severe. Assume that society is trying to make the following choice. It knows that if by sacrificing \$1 million of consumption today, it can increase consumption in future periods by \$1 per period. Would society choose this alternative? It would if the discount rate were zero. Why? What has it lost? It has lost \$1 million today. But what has it gained? One dollar is gained in each period for an infinite number of periods. The present value of the gain is infinite and the cost is finite. Society will want to sacrifice any amount today if it generates some increase in benefits in an infinite number of future periods, independent of how small those benefits are in each future period. As the discount rate increases from zero to infinity, the present value of future consumption decreases, i.e. the concern for future generations lessens. As can be seen, the social rate of discount reflects important social choices.

The problem is now completely defined and the fishery manager can determine how the stock can be utilized to maximize its contribution to society's welfare. We begin to solve this problem by asking what is the benefit to society of harvesting one more fish in the current period (s,s=0)? How much enjoyment or utility will society gain this year if it catches one more fish this year? The benefit has been assumed to equal p (the price of fish), the opportunity cost of catching that fish is c(x), so the net benefit to society in the current period of catching one more fish is p - c(x). The net benefit to society of harvesting h fish in the current period is therefore $[p-c(x)]\,h(0)$. Now, what is the net benefit to society in the current period s of harvesting some amount of fish in some future period $(t, t > 0)$, i.e. what is the present value to society of catching in period t some amount of fish h(t)? Price (p), assuming the price remains constant, minus the cost (c(x)), multiplied by the amount of fish harvested in that particular period (h(t)), is the net benefits $[p-c(x)]\,h(t)$ that accrue in the future period. To express these in terms of their present value, they have to be discounted back to the current period using the social rate of discount $(e^{-\delta t}[p-c(x)]\,h(t))$.

What, then, is the present value of the net benefits society will derive over time from exploiting our imaginary fish stock at some rate h(t), $t = 0,1,2,\ldots,\infty$? The present value of exploiting a fish stock at some rate h(t) is the integral from time zero, the current period, to infinity (∞) of the net benefits to society in each period from harvesting the fish, discounted back to the present using the social rate of discount (δ).

$$PV = \int_0^\infty e^{-\delta t}[p-c(x)]\,h(t)\,dt \quad .$$

If we know h(t), the path of h over time, we can calculate the present value to society of exploiting the stock at that particular rate.

The manager of our fish stock wants to choose that rate of exploitation of the stock h(t) that maximizes the stock's present worth, or present value, to society. In order to do this, he must choose that path of h(t) which maximizes $PV = \int_0^\infty e^{-\delta t}\,[p-c(x)]$

$h(t)dt$. When the fishery manager is appointed there is some initial finite stock (x_0). Because the resource is scarce, he cannot choose to harvest an infinite amount of fish in each period. The scarcity of both fish and fishing effort makes a trade-off between the current period and future periods inevitable.

The manager's maximization problem also is constrained by a number of other factors, all of which have previously been introduced, so they will only be summarized here. The stock grows at some natural rate $F(x)$. The manager is also constrained by the technology at his disposal, that technology is described with the harvesting function, $h = g(x)E$, where $0 \leq h(t) \leq h_{max}$. The rate of change in the stock at any point in time $(\frac{dx}{dt})$ is therefore just $F(x)$, the natural growth rate, minus the harvesting function

$$\frac{dx}{dt} = F(x) - h(t) \quad .$$

The rate of change in the population at any point in time is being constrained by two facts: the biological limitations of the population's size and growth rate, and the harvesting function. For obvious reasons the stock $x(t)$, at any point in time t, must also be greater than or equal to zero. All of these constraints are manifestations of the fact that society's resources are scarce.

The fishery manager therefore must find that path of $h(t)$ through time which maximizes

$$PV = \int_0^\infty e^{-\delta t} [p - c(x)] \; h(t)dt$$

subject to

$$\frac{dx}{dt} = F(x) - h(t) , \quad c(x) = w/g(x) ,$$

$$0 \leq h(t) \leq h_{max} , \quad x(0) = x_0 , \quad x(t) \geq 0 \quad .$$

The mathematical techniques that are required to solve this problem will not be discussed here.[7] We examine only the form of the solution and ask what, if anything, can be inferred.

In the world defined above with its simple harvesting function and

7. For a discussion of the derivation of the solution see either C. CLARK, *supra* note 2, or Clark & Munro, *supra* note 2. An introduction to dynamic optimization can be found in M. INTRILLIGATOR, MATHEMATICAL OPTIMIZATION AND ECONOMIC THEORY (1971).

its simple population dynamics, the solution to the fishery manager's problem has the following properties. There is an optimal stock size (x^*) that once achieved will always be the optimal stock size. It will not fluctuate through time. Pulse fishing is therefore not appropriate.[8]

It also turns out that the optimal stock is that x^* for which

$$1/\delta \; [d/dx^* \{[p - c(x^*)] F(x)\}] = p - c(x^*) \quad \cdot$$

The equation says that in every period we should deplete the stock, i.e. harvest fish, until the gain to society in the current period from catching the last fish equals the loss to society in future periods since one more fish was caught today, rather than being saved for a future period. So, the $h^*(t)$ should be chosen that equates the marginal benefit that society derives from the last fish it catches today with the marginal cost society incurs from catching that last fish. It is a very simple rule: fish up to the point where the marginal benefits from fishing equal the present value of the marginal cost of fishing. At that point one is maximizing the present value of the net benefits from the fishery to society.

The right hand side of the equation represents the net benefits society derives in the current period from the last fish caught. It is the benefits to society (p) from catching one more fish in the current period, minus the current cost of catching that fish ($c(x^*)$). What does the left hand side say? Let us examine it one term at a time. The phrase $[p - c(x^*)]$ can be interpreted as the net benefits to society in any peiod of catching one more fish in that period. This is multiplied by $F(x^*)$, which is the natural growth rate of the population when we have a population size x^*. It is also the sustainable yield, the amount we can catch in every period from the stock x^*. Therefore, $[p - c(x^*)] F(x^*)$, is sustainable net benefit to society in each period from having a stock of x^*. Why? Because this is the number of fish society can catch in each period on a sustainable basis, multiplied by the net benefit each of these fish brings society in that period. The differential of this expression with respect to x^* $[d/dx^* \{[p - c(x^*)] F(x)\}]$ indicates how much of those sustainable net benefits in each future period are reduced if we make a slight move from equilibrium by catching one more fish in the current period (reduce the stock, x^*, by one fish). When we are in equilibrium and then increase fishing a little in the current period, we reduce sustainable net benefits in future periods. When the derivative is multiplied

8. Pulse fishing is characterized by a situation where the stock is heavily fished in one period, then not fished for several periods, then again heavily fished. The distant water fleets of Japan and Russia often fish in this manner.

by $(1/\delta)$, the reduction in sustainable net benefits is in terms of its present value. The left hand side of the equation is therefore the present value of what society is sacrificing in the future because it caught one more fish today. The equation therefore expresses the fact that the fishery manager wants to equate the marginal present gain from fishing with the present value of the marginal future loss; and that once x^* is in fact reached, he will want to maintain the stock at this optimal size, this implies harvesting at the sustainable rate $F(x^*)$.

When the fishery manager is appointed, the stock is probably not at the level x^*, $x(0) = x_0$, where $x_0 \neq x^*$. The adjustment of the stock to x^* is quite simple. If the initial stock size, x_0, is greater than x^*, fish should be harvested at the maximum rate, h_{max}, until the stock has reached its optimum level. If x_0 is less than x^*, fishing should be stopped until the stock builds up through natural growth to the optimum level. The solution to the fishery manager's problem says the stock should be adjusted to its optimum level at maximum speed.[9]

9. This particular solution to the optimal control problem depends critically on the simplifying assumptions made.

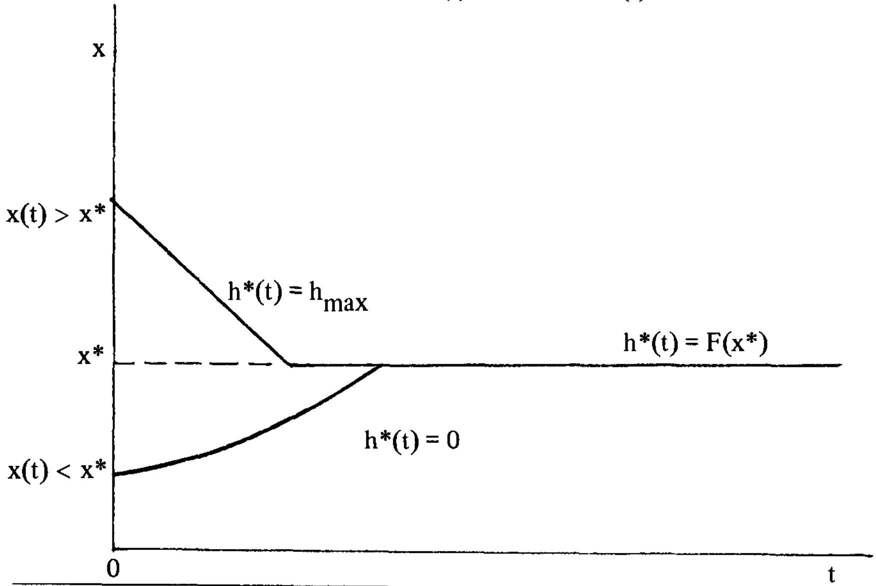
(1) The "bang-bang" approach results from two factors: (a) harvesting costs are independent of the speed with which the fish are harvested $[C = hc(w), \partial^2 C/\partial h^2 = 0]$; and (b) the price of fish is independent of the speed with which they are harvested (and sold)—the fishery manager was assumed a price taker. Therefore, there is no cost to adjusting the stock size at the maximum speed ($e^{-t}[p - c(x)]h(t)$ is linear in the control $h(t)$). A more complicated adjustment process would result if we allowed for a non-linear harvesting function and made the price of fish a function of the amount sold $(p = p(h))$. When these complexities are introduced, the manager's objective becomes to maximize $PV = \int_0^\infty e^{-\delta t}[u(h) - c(x,h)]\,dt$, where $u(h)$ is society's utility function for fish $(u'(h) > 0,\ u''(h) < 0)$. The utility function replaces p in the objective function because when $p = p(h)$, p no longer reflects the social value of a fish. The integrant, $g(x,t,h) = e^{-\delta t}[u(h) - c(x,h)]$, is now non-linear in the control $h(t)$. Two cases are possible. If the marginal cost of fishing is increasing $[c(x,h) = x(x)\phi(h)$, where $\phi(h) > 0$, $\phi' > 0$, and $\phi''(h) > 0]$, then $g(x,t,h)$ is concave in h. In this case $x^*(t) = x^*$ (it remains constant over time), but now a smooth asymptotic adjustment to x^* is appropriate if the initial $x \neq x^*$. However, if the marginal cost of fishing is decreasing in the appropriate range $[\phi''(h) < 0]$, $g(x,t,h)$ could be convex in h. Then an optimal control and stock size, h^* and x^*, do not exist. Pulse fishing will be appropriate (the harvesting policy of some of the large distant water fleets). *See* C. CLARK, *supra* note 2, at 166.

(2) The optimal stock size in the basic model (x^*) is autonomous (it does not vary over time, $x^*(t) = x^*$) because price, cost and the discount rate are constant over time. Alternatively, one could have assumed that price varies over time $(p = p(t))$, and that costs decrease over time due to Hicks neutral technical progress (replace $h\,c(x)$ with $h\,\phi(t)c(x)$, where $\partial\phi(t)/\partial t < 0$). The result is that $x^* = x^*(t)$, such that at any point in time

$$\frac{1}{\delta}\left[\frac{\partial}{\partial x^*}\left\{[p(t) - \phi(t)c(x^*)]\ F(x^*) + p(t)x^* - \phi(t)c(x^*)x^*\right\}\right] = p(t) - \phi(t)c(x^*).$$

FIGURE 3

Optimal Paths for h(t), and in turn x(t).



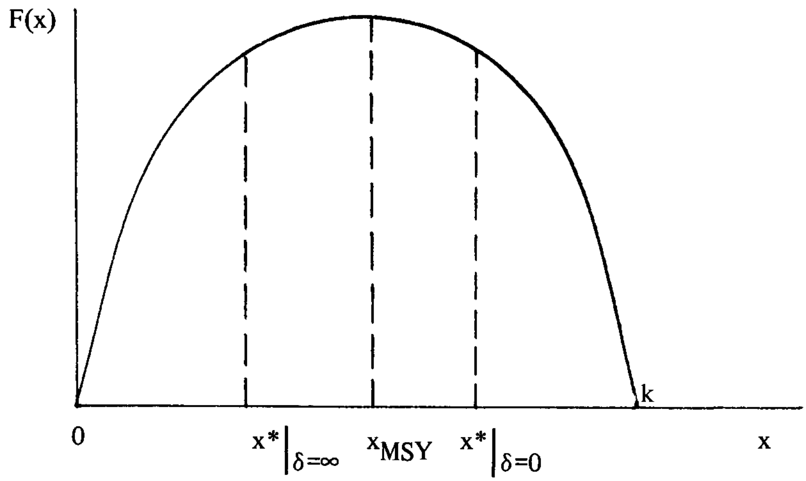
See Clark & Munro, *supra* note 2, at 98. One might contrast this decision rule with the autonomous one. It is of interest to note that this nonautonomous decision rule is myoptic ($x^*(t)$ depends on the current rates of change in prices and costs ($p(t)$ and $\phi(t)$) but not on their future rates of change).

(3) The basic model implicitly assumes that the capital imbedded in fishing effort is perfectly mallible. One could have alternatively assumed that once capital is invested in fishing (a boat for example, which must be purchased at price π), it cannot be transferred to other uses (there is no second hand market for boats or their scrap). The model can be modified to examine this case by assuming that one unit of E is the use of a standardized fishing boat for one season, and by adding the constraints that: (1) $0 \leq E(t) \leq E_{max} = K(t)$, where $K(t)$ is the number of fishing boats at time t; and (2) $0 \leq \dot{K}(t) = I(t) \leq +\infty$; ((2) is implied, if for example, there is no resale market and the boats do not depreciate). Our basic model implicitly assumed that $-\infty < K(t) = I(t) < +\infty$ and that $\pi = 0$ (there is an operating cost but no fixed cost associated with the use of the capital). In the perfectly nonmallible case (no resale and zero depreciation) the fishery manager maximizes the PV of his firm by first purchasing all his capital (he buys an additional boat if its contribution to PV is greater than its cost (π)), and then determining the optimal stock size x^* given this fixed stock of boats ($E_{max} = K(t)$). If we assume that $K(t)$ is greater than or equal to the equilibrium amount of capital utilized in the perfectly mallible case outlined in the text (this will often be the case), then the optimal stock size x^* is the same in both cases (the perfectly mallible and the perfectly non-mallible)—the same decision rule holds. This follows because once the boats are purchased (in the nonmallible case), the two models are effectively the same, only operating costs are relevant and the manager is free to use as many or few of those boats as he wishes. If $K(t)$ is greater than the amount of capital required to harvest $h^*(t)$, the firm will be characterized by "excess capacity." One should note that it was optimal to create this excess capacity and it is optimal to let it remain idle (just because the boats exist does not mean they should be utilized). For a more complete discussion of nonmallibility see Clark, Clarke & Munro, *The Optimal Exploitation of Renewable Resource Stocks: Problems of Irreversible Investment*, 47 ECONOMETRICA 25 (1979).

Recall that the graph of our simple growth function for the fish stock is

FIGURE 4

The Relationship Between the Optimal Stock Size (x^*) and the Rate of Discount (δ).



Assume that if the discount rate is zero, the optimal stock is $x^*\big|_{\delta=0}$ and if the discount rate is infinity, the optimal stock is $x^*\big|_{\delta=\infty}$. Figure 4 is drawn such that $x^*\big|_{\delta=\infty}$ is to the left of the stock size that maximizes sustainable yield (x_{MSY}) and $x^*\big|_{\delta=0}$ is to the right of x_{MSY}. Given our assumptions it could in fact be this way, but it is not required. The assumptions only require that $x^*\big|_{\delta=0}$ is to the right of $x^*\big|_{\delta=\infty}$ and $\geq x_{MSY}$.

If the social rate of discount δ is between zero and infinity, the optimal stock size (x^*) is $x^*\big|_{\delta=0} > x^* > x^*\big|_{\delta=\infty}$. When the discount rate is zero, benefits and costs in future periods are evaluated the same as benefits and costs that occur in the current period. Since society is concerned about the effects of depletion on future generations, it wants a relatively large stock in the current period. One also knows that as the discount rate increases, as society cares less and less about future generations, the optimal stock size declines. Why?

When society in the current period is evaluating the loss to future periods from catching one more fish today, it discounts it back to the present using δ.

When economists started working on the fishery manager's problem, they generally made the implicit assumption that the discount rate was zero.[10] The maximization problem (max $PV = \int_0^\infty e^{-\delta t} [p - c(x)] h(t)dt$, given $\delta = 0$), reduces to maximizing the sustainable net benefits from fishing (max $[p - c(x^*)] F(x^*)$). This was the goal that economists first proposed. It is not valid, however, unless $\delta = 0$.

We have defined the stock size that maximizes sutainable yield as x_{MSY} (see figure 4). There is no reason to suspect that maximizing sustainable yield is the appropriate goal (i.e. that $x^* = x_{MSY}$). x_{MSY} will equal x^* by only the merest coincidence. The appropriate goal is not to maximize sustainable yield. This point is stressed because x_{MSY} is often the stated goal of fishery policy. Maximizing sustainable yield will not, in general, maximize the present value of society's net benefits from the fish stock.

It is interesting and revealing to determine the conditions under which x^* would equal x_{MSY}. The optimal stock size (x^*) can possibly equal x_{MSY} if none of society's resources, besides fish, are required to catch fish, i.e. if no fishing effort (E) is required to harvest fish. Then the opportunity cost to society in the current period of catching the last fish is zero ($c(x) = 0$).[11] Therefore maximizing $PV = \int_0^\infty e^{-\delta t} [p - c(x)] h(t)dt$ reduces to maximizing $\int_0^\infty e^{-\delta t} ph(t)dt$. Now, further assume that $\delta = 0$. If $\delta = 0$ and $c(x) = 0$, then maximizing the stock's present value reduces in the limit to maximizing $pF(x^*)$. The price (p) is given from the fishery manager's point of view, so he wants to maximize $F(x^*)$. In which case $x^* = x_{MSY}$ by definition. If the social rate of discount is zero and if no effort is required to harvest fish, the optimal stock produces the maximum sustainable yield. Advocates of x_{MSY} as the goal of fishery management have, for one, failed to consider the opportunity cost to society of

10. *See, e.g.*, Gordon, *Economic Theory of a Common Property Resource: The Fishery*, 62 J. POLITICAL ECON. 124 (1954). On the other hand, see Scott, *The Fishery: The Objective of Sole Ownership*, 63 J. POLITICAL ECON. 116 (1955), which recognized that the sole owner (or manager) would want to "maximize the present value (future net returns discounted to the present) of his enterprise."

11. If effort (E) is required to harvest fish but has no other uses in society (i.e. its opportunity cost is zero), then fishing costs ($c(x)$) are also zero.

using its scarce resources to catch fish. They forget about the cost of catching fish.

REGULATION

We begin this section by examining the unregulated fishery where fishing is completely uncontrolled: anyone can fish at any time. First we will consider whether a stable equilibrium can exist in such a fishery, i.e. whether an unregulated fishery will reach a point where the stock remains stable through time, or whether the stock size will fluctuate and possibly be driven to extinction. Then we want to give the theoretical reasons why the fishery must be managed or regulated. Free competition in the fishery will not lead to the socially optimal rate of exploitation.

A fishery where anyone can fish any time and which is completely unregulated is a common property fishery. A common property resource is a resource that is not effectively owned by anyone. By ownership we do not mean ownership in the legal sense of the word, but rather that one effectively controls the use of the resource. Ownership, by this definition, is synonymous with control.[12] The air, water, and wild animal species such as fish are all examples of common property resources. The lack of property rights for these resources had lead to their misuse. Perfect competition cannot effectively allocate common property resources, the free market fails.

The amount of effort allocated to the common property fishery over time will not be the optimal amount. There are many fishermen and each must decide how much effort to allocate to the fishery. Each fishing boat owner wants to supply the amount of effort to the fishery that maximizes the present value of his future stream of profits. Profits (π) for the fisherman in some period t are total revenue, the total amount of money he takes in (the price of fish times the number of fish he harvests ($p \cdot h$) minus total costs ($c(x)(h)$: $\pi = [p - c(x)]\, h$.

Imagine for the moment that instead of many fishermen working this stock there is only one. Assume he owns the stock.[13] He can

12. One does not own an item if its use is controlled by others or if someone can take it without retribution. When we talk about the ownership of a fishery, or lack of it, we mean the exercise of effective control. Is there an individual, a government, an agency, etc., which has the power to decide what they want done with the fishery and the ability to enforce their decision? If not, it is a common property resource.

13. One should not confuse this sole owner with a monopolist. The sole owner is the owner of just one of many distinct stocks of fish. He has effective control over this one fish stock but absolutely no control over the market in which he sells his fish, or the market in which he purchases his inputs.

completely control the access of other people to this stock. Given such a situation, this individual wants to maximize the present value of his profit stream, $PV = \int_0^\infty e^{-rt}[p - c(x)]\,h(t)\,dt$. This is identical to the formula that the fishery manager had to maximize to achieve the socially optimal rate of exploitation of the fish stock. If the social rate of discount is equivalent to the rate at which this individual can borrow or lend in the market place (r), if the parametric price (p) he sells his fish for reflects its social value, and if his private costs equal the social costs, then this individual, who is just trying to maximize his own profits and achieve his own self interests, will harvest fish at the rate that maximizes the social welfare society derives from the fish stock. Under this set of restrictive assumptions what the individual does in his own self interest is equivalent to what would be best for society.[14] This result requires both pure competition and private ownership. The individual, because he has effective control of the stock, harvests it at the socially optimal rate.

The sole owner can substitute future harvesting for current harvesting. He is able to fish less today and therefore more tomorrow when he feels such a reallocation of fishing effort will increase the present value of his profit stream. He could, for example, stop fishing and let the stock increase through natural growth. If he decides to conserve, he will be able to reap the rewards of that conservation in the future. Why? Because he has effective control over the *life* of the fishery: he has ownership *tenure.*

Now let us go back to the other case, where there is not a single owner, but a multitude of fishermen. This is the common property situation where access is open to anyone who wants to fish. In such a case the fisherman cannot trade current harvesting for future harvesting. The individual fisherman in a common property resource is unable to reap the rewards of his conservation. The fisherman who decreases his current fishing now so there will be a larger stock in the future, will be frustrated in his attempt. Another fisherman will catch the fish if he does not, because he cannot control access to the fishery. His harvest rate today has no effect on the size of the stock in future periods because he is just one of many fishermen, and he cannot control what the others do. Therefore, the individual fisherman in the common property fishery, when he decides what to do in the current period, will not concern himself with the size of the stock in the future. He is effectively forced to use a discount rate of infinity. When the discount rate is infinite, the present value of any future benefits or

14. This is Adam Smith's invisible hand at work.

costs that take place is zero. In the common property fishery the individual fisherman operates as if his effective discount rate were infinite, as if the future did not matter. Why? Because even though he is concerned about future stock sizes he can do nothing about them. His only concern is to maximize current profits, $[p-c(x)]h$ (in the limit $\int_0^\infty e^{-\delta t}[p-c(x)]\, h(t)dt \rightarrow [p-c(x)]\, h$ as $\delta \rightarrow \infty$). The individual fisherman is forced to act in a socially suboptimal manner because he is forced to ignore the effects his current fishing will have on the stock size and in turn on future harvests. His behavior will only be optimal if the social rate of discount is in fact infinity.

Now assume a transitory situation where each of the fishermen in the common property fishery is earning a profit. Their total revenues are greater than their total costs ($\pi > 0$). They are earning a rate of return greater than their opportunity cost (i.e. excess profits). Under these circumstances effort previously allocated to other industries will move into the fishery. The increased fishing will cause the stock size to decrease and the cost of fishing to rise. As costs rise profits decline. Entry will continue until profits are reduced to zero. Alternatively assume a transitory situation where there is too much effort allocated to the fishery. The owners of that effort would then be earning less than their opportunity cost, i.e. less than they could have earned if that effort had been allocated to some other industry. Over time effort will exit or leave the industry until profits gradually increase to zero. The common property fishery will not be in equilibrium until profits and losses are driven to zero. Fisherman, in equilibrium, are earning their opportunity cost, the value of what they could have produced in the next best alternative.

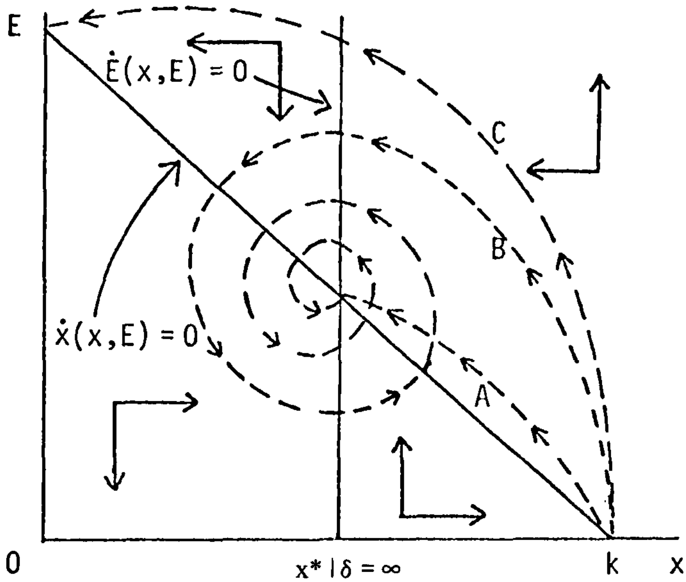
We can characterize the common property fishery in three ways: (1) Each individual fisherman is effectively forced to utilize a discount rate of infinity, and thus, to maximize his current profits rather than the present value of his future stream of profits. (2) Since there is free entry into this fishery profits are driven to zero in the long run. (3) The equilibrium stock ($x^* \big|_{\delta=\infty}$) is that which would be socially optimal only if the discount rate was infinity (see Figure 4).[15,16]

15. Empirical applications of this model are limited. *See* Henderson & Tugwell, *Exploitation of the Lobster Fishery* 6 J. ENVT'L ECON. & MANAGEMENT 287 (1979), which estimates the equilibrium stock sizes (and harvest rates) for two open-access lobster fisheries. Optimal stock sizes and harvest rates were also estimated and used to measure the magnitude of the welfare loss due to common property exploitation of these fisheries. *See also* Wilen, *Common Property Resources and the Dynamics of Overexploitation: The Case*

When there is a common property resource, what is in the interest of the private individual is not necessarily in the interest of society. The private cost incurred by the individual fisherman is less than the social cost. His costs to catch one more fish are the amount of effort that he is using to catch that fish in the current period, i.e. the op-

of the North Pacific Fur Seal, (September 1976) (Resources Paper No. 3, University of British Columbia), which empirically estimated a model explaining the common property exploitation of a fishery.

16. It is of interest to examine the path to equilibrium. Will the industry adjust smoothly or cyclically? Can the adjustment path lead to extinction even through $x^* > 0$? To answer questions of this type one must specify the rate at which effort enters (exits) the industry as a function of excess profits (losses). The implicit assumption so far has been that the adjustment to equilibrium, $\pi = [p - c(x)]\ h = 0$, is instantaneous. One might more realistically assume that $\dot{E}(t) = k_n$, where $n = 1$ if $\pi \geq 0$ and $n = 2$ if $\pi < 0$. Assume that $k_1 > k_2 > 0$ (it is easier to enter than to exit). Many disequilibrium adjustment paths are now possible. Three of them are outlined in the following plane diagram.



Path A represents a smooth adjustment from the unexploited state to the competitive equilibrium. Path B reflects a situation where the existence of profits, when exploitation begins, leads to excessive entry (K_1 and k_2 are large). This is followed by an overreaction to the resulting losses. Equilibrium is approached but along a cyclical path. Path C leads to extinction. It reflects a case where entry costs are now leading to excessive entry (high k_1) combined with the inability to exit when losses arise (k_2 is very low). Path C might reflect a situation where the government encourages entry into the unexploited fishery (using subsidized loans for boats, etc.), but exit is hindered because the boats have no alternative use or scrap value. *See* Smith, *Economics of Production from Natural Resources,* 58 AM. ECON. REV. 409 (1968). *See also* Wilen, *supra* note 15, for an estimate of a dynamic model of the competitive exploitation of the North Pacific Fur Seal between 1880-1900. Wilen's data suggest that this particular common property fishery was on a convergent cyclical path (similar to path B) when the Canadian fleet was monopolized in the early 1900's.

portunity cost of his effort. The fisherman does not consider losses to future generations because he caught that fish today. However, the cost to society is both the opportunity cost of the effort used in the current period and the present value of the loss to any future generations. There is a wedge between private costs and social costs. Therefore the individual acts contrary to the social interest. This is why the common property resource must be managed. If the fishermen were working in the interests of society, i.e. if a strategy that maximized his own profits also maximized the fishery's contribution to society, then there would be no reason to manage the fishery. The common property problem results because no one owns the fish. If someone did own the fish, he could charge the fishermen for each fish caught and private costs, would ideally, equal social costs. Unfortunately, access to the fishery is free. Except for the effort the fisherman has to use, he can take fish out of the ocean for free. This results in a misuse of both the fish and the fishing effort.

This lack of ownership or control also causes air pollution problems. No one owns the air; no one can effectively control its exploitation, therefore pollution rates are not socially optimal. Why? The private costs to the individual, for example to the factory, of discharging one kilo of garbage into the air is less than the cost to society of that discharge. The factory does not have to pay for the air it uses so the private cost is lower. People are polluting at an excessive rate because of this difference between society's opportunity cost and the private cost. This problem is comparable to the problem in the fishery: in one case productive factors (fish) are removed from the common property resource; in the other case negative productive factors (garbage) are dumped into the common property resource. In both cases the stock is exploited at a socially non-optimal rate.

Let us now consider ways to regulate the fishery to achieve the socially optimal rate of exploitation.[17] Taxes, quotas, and gear regulations will be examined. Since the fishery manager wants to maxi-

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17. Up to now the fishery has been characterized by free access. Suppose the fishing authority has, by government decree, obtained the legal rights to the fishery. Assuming that the government can effectively control the fishery, the common property problem is in theory solved. The government can run the fishery as a profit maximizing public corporation, or sell the property rights to a private corporation. Either of these two alternatives would constitute a major rearrangement of society's institutions so one would expect many people to object. There is also the practical problem that many fish stocks are large and migrate over vast geographical areas. The fishing corporation (be it private or public) would have control over a huge amount of resources with an extremely high present value. Probably no private group could afford to buy the property rights from the government. One might also expect diseconomies of scale (increasing long-run average costs) to arise in such a large corporation.

Up to this point we have assumed that the price of fish is parametric to the owner of the mize the stock's present value to society, he should adjust the stock until the net benefits from the last fish caught in the current period equals the present value of the loss to future generations because that one extra fish was caught today. This is the intertemporal rule which determines the optimal harvest for each period. The fishery manager wants to harvest fish so as to satisfy the intertemporal rule and he wants to do it utilizing the harvesting technique that minimizes his cost. The fishery manager has to use the harvesting technique that minimizes the opportunity cost of catching the appropriate amount of fish. We have been assuming that the cost, c(x), is the minimum cost of catching the last fish.[18] Optimal use of the resource requires that fish are harvested efficiently, i.e. that resources are not wasted. The fish stock will be exploited optimally only if both the intertemporal rule is fulfilled, and if at any point in time for any rate of harvesting, the opportunity cost of catching the appropriate amount of fish is minimized. Many existing regulatory schemes introduce the latter type of inefficiency by forcing the fishermen to harvest fish in a way that does not minimize the opportunity cost to society. For example, fishermen are often required to use inefficient gear. A regulation that institutionalizes waste is inconsistent with the socially optimal use of a fish stock. The wasted resources could have been used to produce other items that society valued. Wasting resources results

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stock, but, given the actual large size of many stocks, this assumption is often untenable. The owners of large stocks could possibly exercise some monopoly power, both in the market for their fish and in the markets in which they purchase units. This possibility makes private ownership of the stock unattractive, excessive market power will cause a misallocation of the fish stock and the fishing effort. These problems could be overcome if enforceable property rights could be created for subsections of the fishing ground. Unfortunately this is not feasible, the enforcement costs to maintain such property rights would be prohibitive.

Therefore the most viable arrangement for the fishery is one in which the government holds the rights to the stock. The question becomes one of whether the government should manage the fishery as a public firm or modify the existing market method of allocating inputs to the fishery. The market form of organization is characterized by many separate economic agents using shortrun contracts to exchange (allocate) their goods and factors amongst alternative uses. The market does not operate within the confines of the firm. The firm hires inputs on a longterm basis and then allocates them by management decree. The government should obviously choose the organization of factors (firm or market) which minimizes the costs of regulating the fishery. *See* Coase, *The Nature of the Firm,* 4 ECONOMICA 386 (1937). Diseconomies of scale would therefore favor a modified market organization. An implicit belief in diseconomies, and an aversion to the changes in social institutions required to create a public firm, causes most economists and policymakers to favor regulation of (rather than usurpation of) the market mechanism. Our discussion of regulation will be in this tradition. R. Hannesson mentioned an additional reason to prefer market regulation over a large public firm. The small private firms operating in the market place have an incentive (profit maximization) to behave optimally given the correct signals (tax rates, etc.) but public firms often lack this incentive.

18. *See* note 5 *supra.*

in fewer goods than would have been possible if resources had been used more efficiently.

There are a number of ways for the fishery manager to optimally regulate the size of the stock when harvesting is a function of two inputs only, the stock (x) and fishing effort (E). In this simple world a quota could be placed on total catch at time t. The quota should equal F(x*). Alternatively, the manager could put a quota on the amount of effort used, setting an upper limit on effort (E) equal to the amount that would achieve the optimal harvest rate (F(x*)) and the optimal stock (x*).[19] A tax on the catch is another regulatory device. A per unit tax on catch would affect the fishermen's costs; private costs could therefore be adjusted until the amount of fishing that maximizes the fishermen's profits is equivalent to the amount that maximizes society's welfare. The harvest rate can be adjusted to any level by taxing the catch or effort, since both affect the private but not social costs. A tax on effort must be set so as to equate the private with the social costs of fishing. The individual's selfish interests are then equal with society's interests. From a purely theoretical point of view, in this simple world, where we have only one variable input, fishing effort, social optimality can be achieved in a number of ways.

Unfortunately, reality is not so simple. Fishing effort (E) is an aggregate or index of many different inputs: fishermen's time, different types of capital, and processing plants. We have been simplifying the approach by aggregating them and calling them effort. In actuality, fishing effort is notoriously difficult to quantify and observe. What often happens in practice is that neither quotas nor taxes are placed on efforts, but rather they are placed on some of the inputs that go into this effort aggregate. While fishing effort is made up of many inputs, fishery authorities restrict only single components of effort such as boat size and season length. A selective restriction such as a tax or a quota on only some of the inputs is inconsistent with the fishery manager achieving the socially optimal use of the resources over time. It forces waste (inefficiency) into the harvesting process; fishermen use a harvesting technique that does not minimize the opportunity cost to society of catching the fish. For example, restrictions on fishing boats' size forces fishermen to use a different combination of inputs to catch the same amount of fish. The restriction does not necessarily decrease the catch. Fishermen substitute

19. The possession of a license which allows the individual fisherman to allocate a given number of units of effort to the fishery, is a type of effort quota. The fishery manager can achieve the desired allocation of effort to the fishery by selling the appropriate number of licenses.

other inputs for large boats. Before the authority enacted this restriction, fishermen were choosing the combination of inputs that minimized the cost of catching a given quantity of fish. As soon as they are forced away from that combination of inputs the costs per fish, both to themslves and to society increases. A restriction on only some of the variable inputs introduces inefficiency.

Take another example, restriction on the length of the season, one of the inputs in the harvesting process. No limits are put on the number of fish that can be caught. The season length restriction merely requires that if fishermen want to catch the same amount of fish (something they most likely will do), they have to do it in a shorter period of time. They must use different inputs, the new combination of inputs being inefficient. This regulation institutionalizes waste because it forces the fishermen to use some combination of inputs that does not minimize their costs or society's costs. Thus, if the authorities want a regulatory scheme that is consistent with the optimal use of the resources, it cannot be one that puts restrictions or taxes on *some* of the inputs only. Such a restriction is always going to lead to waste and inefficiency. Inefficiency is not automatically introduced if we tax or restrict *total* effort given that effort can be properly measured.

When there are multiple variable inputs, quotas on the catch also introduce inefficiency into the harvesting process. Limiting the total catch of a large number of fishermen, by itself, introduces waste and results in a race among the fishermen to harvest the fish. Each individual tries to catch as many fish as he can before the quota has been filled. To achieve this goal, he will invest in new equipment: faster boats, boats that hold more fish, etc. He is going to invest in technology (capital) that allows him to catch fish at a faster rate than his competitors. Maybe he will be successful at this for a short while, but eventually most of the fishermen will adopt the same technology and the temporary advantage will be lost.[20] This more expensive technology would not have been chosen if the quota had not been introduced. The introduction of the quota therefore raises the opportunity cost to society of catching each fish. It introduces inefficiency. If the fishery manager wants to maximize the present value of the fish stock to society, he should not use any of these regulatory schemes.

A per unit tax on catch, however, is not, by definition, inconsistent with social optimality. There is nothing about such a tax that either encourages, institutionalizes, or requires the fisherman to fish in an

20. Keep in mind that speed and efficiency are not synonymous.

inefficient way. It does not force him to use strange, primitive, or excessive gear. He is free to choose the input combination that minimizes his cost of catching the fish. Furthermore, since the tax affects the fisherman's costs, it can be used to regulate the size of the total harvest. In theory the tax rate can be set so that the optimal stock size (x*) is achieved. A tax on output is capable of being used to maximize the present value of the fish stock.

Determining the magnitude of the tax is, in practice, a difficult problem. The tax should be set so that the private cost of the last fish caught in the current period is equivalent to the social cost. It must equal the present value of the loss to future generations because one more fish was caught today. This is equivalent to what a private owner, who has the same costs and discount rate as society, would charge people to remove fish from his stock. A tax on catch is consistent with what an economist would describe as social optimality.[21] It also has the advantage of being easy to collect, and easy to enforce, at least easier than gear regulations. However, it is probably politically infeasible to start taxing the fishermen for the fish.[22]

Fishery regulation is a complicated topic that we have discussed

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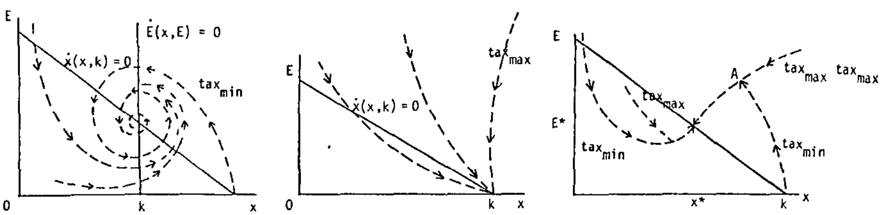
21. When one takes account of the fact that effort does not adjust instantaneously to dissipate all rents in the fishery (π = p - tax - c(x) h)–*supra* note 17–the single tax solution is replaced by the need for as many as three taxes. *See* Clark, *supra* note 2, at 118. The main points of Clark's arguments are reproduced here. The equilibrium tax (tax*) remains the same but it will not lead to the desired most rapid adjustment to x*. A most rapid approach can best be achieved by using some combination of tax_{max} and tax_{min} where tax_{max} > tax* > tax_{min}. This can be seen by examining the adjustment paths given tax_{max} and tax_{min}. They might appear as follows:



Now identify the optimal equilibrium (x*,E*) along with the t_{max} and t_{min} adjustment paths which lead to this point. If, for example, the fishery is initially unexploited (pt. k), x* is most rapidly approached by first taxing the fish at tax_{min} (this might imply a zero or negative rate) then switching to tax_{max} when pt. A is reached. Tax_{max} is then maintained until equilibrium is achieved at which point the tax is permanently switched to tax*.

22. The fishermen will fight the introduction of taxes (or other regulatory schemes) designed to eliminate the inefficiencies resulting from the common property nature of the fishery. *See* Weitzman, *Free Access vs. Private Ownership as Alternative Systems for Managing Common Property,* 8 J. ECON. THEORY 225 (1974), where it was shown that fishermen as a group, are better off when the fishery is open access than they are when the fishery is efficiently managed.

only briefly. The extent of its treatment here is sufficient to make one point: one should be wary of any regulatory scheme that deliberately introduces inefficiency into the harvesting process. If the goal is to use the fish in a way that brings the greatest welfare to society, one should not use a type of regulation that inherently wastes some of society's scarce resources.

We will finish by examining the problem of unemployment among fishermen. This is just one of the many ways the model can be applied. For simplicity assume that fishing effort consists only of the fishermen's time. There is no need for fishing boats or other equipment. One combines fishermen's time with the stock size to harvest fish. Also assume the fishery faces the following problems: the unemployment rate among fishermen is quite high; there is a tendency for the unemployed to move from fishing communities to urban areas in search of jobs; the government, however, wants the people to remain in the small communities so present population patterns are maintained.[23] This problem can be analyzed within the framework of our simple model. The fishery manager still wants to maximize the present value of the fish stock ($PV = \int_0^\infty e^{-\delta t} [p-c(x)] h(t)dt$), where $c(x)$ is still the opportunity cost to society of catching a fish. Furthermore, $c(x)$ equals $w/g(x)$, where w is the opportunity cost of one unit of fishing effort. The value of what one unit of effort could have produced if it had not been allocated to the fishery is represented by w. If fishing effort is equivalent to fishing time, then w is the opportunity cost of the fisherman's time. Originally we assumed that the fisherman's wage was determined in some competitive market and was given from the point of view of the individual fishery. The wage therefore, reflected the opportunity cost to society of using one more unit of effort, one more hour of the fisherman's time. Obviously this is not true in the case just described, where there is unemployment and the government discourages mobility. We can no longer argue that the fisherman's wage is the true opportunity cost to society of allocating an hour of his time to the fishery since some of the fishermen are unemployed. The money wage rate must be adjusted until it reflects the true opportunity cost to society of using this labor to catch fish. Unemployment, and the lack of mobility, affect only w. The fishery manager still wants to maximize the present value of the stock after he determines the appropriate magnitude for w.

What is the opportunity cost (w) if these unemployed fishermen spend one more hour fishing? If they could have moved to an urban

23. A situation characteristic of Northern Norway and the East coast of Canada.

area and obtained a job, then their social opportunity cost would normally have been the value of what they could have produced in one hour at this job. If the government discourages moving, this is not the case. In effect, then, all their alternatives should be in the geographical area where they presently reside. We cannot therefore consider as an opportunity cost something they could have produced outside of this geographical region. The government is placing limitations on the fishermen's alternatives, limitations on the goods they could have produced if they had not been fishing. In the geographical region in which they live, there are apparently not that many alternatives, otherwise they would not be unemployed. To simplify the problem's exposition, assume that the fishermen have no employment alternatives. The cost to society to allocate one more unit of this effort to fishing is therefore zero. If the individual had not been fishing, he would have been unemployed and therefore would not have produced any other goods or services. His opportunity cost is zero.[24] Therefore, the optimal rate of exploitation of the stock will be that harvest rate which maximizes PV $\int_0^\infty e^{-\delta t}\, ph(t)dt$. There are no costs to be considered. A tax on per unit catch can still be used to achieve the optimal harvest rate, but in this particular case it might turn out to be a negative tax, a subsidy. A negative tax could be necessary because the private costs to the employer of hiring one more unit of effort is the money wage, but the social cost is zero since the employee has no alternatives. Therefore the private fishing costs are possibly greater than the social costs. A subsidy is then required to equate the two. The purpose of the discussion here has not been to thoroughly treat the unemployment problem in the fishery, but rather to show how one might generalize or modify this simple model to consider some of the complications of the real world.

The intent of this paper has been to introduce the theoretical framework an economist would use to examine the common property problem in the fishery. Although this model has been simple, the important points have still been elucidated. They would have been obscured in the complexities of a more general model. Moreover the approach could not have been more policy orientated. There are no simple applicable rules that can be used to optimally regulate the fishery. Proper regulation requires an understanding of the appropriate economic model and specification of the correct biological model for the stock.

24. Maybe the government has a policy over time of encouraging industry to move into this community. If so, the opportunity cost of the fishermen's time will gradually increase over time as their employment opportunities increase.