Time, Capital Intensity, and the Cost of Fishing Effort

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The notion that a fishing vessel's costs are a function of its "effort" is a useful paradigm in fishery analysis. This paper elaborates on this micro theoretic approach, and proposes a way to view the cost of effort relation as the interaction of capital intensity decisions and the length of the fishing season. The model indicates that capital intensity decisions are affected by season closures, and that season closures can be used to redistribute wealth among different classes of fishermen.

In microanalysis of the fishery it is often useful to view the relation between a commercial fishing vessel and the fishery in the same light as the neoclassical firm–industry relation. This approach was formally proposed by Anderson, who used it to contrast the open access and maximum economic yield solutions and to examine the effects of regulations at both the firm and industry levels. The basis for this analysis is to view a vessel's effort as its decision variable. The vessel's catch rate depends on its total fishing effort and the average productivity of the fishery, which in turn is affected by the effort of all fishing vessels. Since effort effectively becomes the vessel's (intermediate) output, the cost of producing effort is assumed to have "neoclassical" characteristics, i.e., eventually decreasing returns to scale cause marginal costs to increase. As a result, the long-run marginal and average costs are displayed as in Figure 1. The vessel is considered a small enough portion of the fishery to be not only a price-taker, but an "average-returns-to-effort-taker." The vessel owner then optimizes where marginal cost of effort equals fishery-wide average returns to effort.

This paper explores in more detail a special case of the cost of effort relation depicted in Figure 1. This relation has been presumed by several researchers [see Visigilio; Clark, 1980], who, like Anderson, have used it in comparative static analysis of the fishery. But the assumption of increasing marginal cost has been called an "ad hoc formulation" by Clark [1985, p. 90]. And it is not immediately clear that actual costs of producing effort in many fisheries are so well behaved. Casual observation and some limited data suggest that short-run marginal costs of effort are roughly constant. The incremental cost of fishing an extra day, setting and retrieving a net one more time, or setting an extra pot or trap is not an increasing function, at least over the relevant range.[1] If short-run marginal costs are roughly constant, what is implied about fishery models? At first glance, it would appear that the equilibrium number of vessels is indeterminate. Anderson's prediction that entry

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[1] Data from an extensive survey of fishermen's costs and revenues in the Alaska salmon fisheries support the notion that short-run marginal costs are roughly constant [see Larson for a description of the survey and summary of results]. Operating expenses which vary with the time spent fishing—fuel, food, ice, supplies—are a relatively small portion of total costs, and do not increase at an increasing rate as time spent fishing increases.

limitations preserve a portion of the fishery's value could be invalid, and Clark's analysis of fishery regulations would be significantly altered.

In this paper I argue that models which assume increasing costs **are**, in general, valid. Short-run marginal costs in many fisheries do eventually increase, and the application of neoclassical cost curves in the production of effort poses no problem. Other fisheries which appear to best be characterized by constant short-run marginal costs still have increasing long-run marginal costs. The reason is because of the unique role of "time" in the production activities of many fisheries. Access to the fishery is constrained by regulating authorities. This affects the capital investment decision, since larger vessels become less economical as the length of the fishing season is reduced. A related concern is that season closures impose higher costs on highly capitalized fishermen than on less capitalized fishermen. This has implications for the political economy of fishing regulation, since season closures become a tool for redistributing wealth among fishermen who differ in capital intensity.

The argument is presented in the following section. I start with two simple observations which characterize many fisheries and proceed with a simple graphical (and static) exposition. Two implications are discussed in the third and concluding section.

A Model of the Cost of Effort

The first observation, discussed above, is that short-run marginal costs (defined as those within a given fishing season) appear to be constant.[2] The second observation is that, unlike most productive activities, a vessel's access to a key input—the fishery—is often limited with respect to time. Season limitations are sometimes dictated by biological factors, for example, in the case of near-shore capture of an anadromous species such as salmon. But in many more fisheries it is a regulatory agency that forces a season closure, as a means of preventing biological overexploitation of the fish stock.[3] Season closures impose a unique type of cost on participating fishermen. Fishermen make expenditures on capital equipment which cannot be used for a good part of the year. During a fishing season, they are often forced to sit idle or find alternative employment, perhaps in another fishery, while awaiting the re-opening of the fishery. These costs depend in large part on the characteristics of the fisherman's capital stock. We should therefore expect fishermen to consider the length of the fishing season and the prospect of season closures in making capital expenditure decisions.

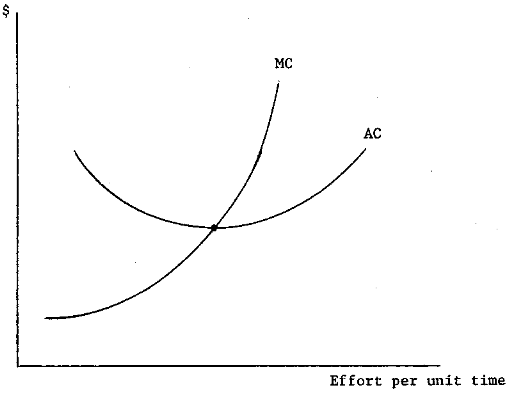

Figure 1. Long-Run Marginal and Average Costs of Fishing Effort.

Consider the following model. In a given fishing season, average cost of effort is a declining function of the time employed in the harvest. However, the biological or regulatory constraint on the length of time one can fish limits each vessel's ability to fully exploit these economies, and the right-hand portion of the short-run aver-

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[2] More accurately, marginal cost is roughly constant only up to some point of "saturation" of the capital stock.

[3] The regulatory constraint is typically binding, even in seasonal fisheries which face biological time constraints.

age cost curve is truncated. Vessel owners can substitute capital intensity for time spent fishing to increase effort, but at some point this substitution becomes uneconomical, as the harvesting capacity of a more capitalized vessel becomes more severely constrained by the time limitation. Over a given fishing season a vessel with fixed capital has average cost of effort which declines with effort (i.e., the time engaged in the fishery). But prior to a choice of "plant size" (i.e., capital intensity), the vessel operator considering the tradeoff of capital and available time to fish faces decreasing returns to capital investment and hence, to effort. In the long-run, marginal cost increases with effort.

To illustrate, express each vessel's total costs c as an increasing function of vessel effort e. Fishing effort is divided into two components, a vessel's capital intensity or "catching power" k, and the amount of time spent fishing during the fishing season t.[4] "Catching power" is a standardized measure of all relevant vessel and gear characteristics, similar to the "standardized fishing unit" commonly found in the literature [e.g., Clark, 1985, p. 38], except that it is a stock measure and does not have a time dimension associated with it. It can also be viewed as including the harvest potential which accrues from the human capital embodied in the skipper and crew. The time component t is consistent with a comparative static framework. It is treated here as an input available to the vessel during the fishing season, and can be thought of as the number of days the vessel is employed during the fishing season. Thus, t is combined with k, up to its maximum allowable level T, to produce effort, which is measured in "standardized fishing unit days." T is set either by biological factors or, more frequently, by a regulating agency. It is assumed that access to any t > T has infinite cost.[5]

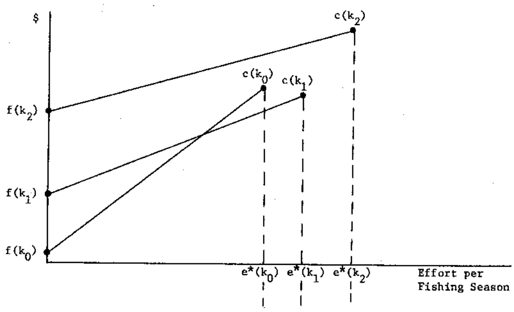

Figure 2. Total Cost-of-Effort Curves for $k_0 < k_1 < k_2$.

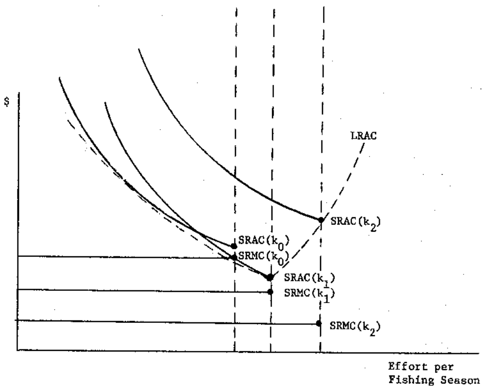

Figure 3. Marginal and Average Cost-of-Effort Curves.

These assumptions imply

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[4] Effort is often treated as an input in the fishery production function. This model is consistent with this practice, only the process is taken back one step to examine how effort is produced. See Karpoff for a more complete model of fishery revenues and costs.

[5] More generally, fishing beyond T has a finite expected cost, e.g., the expected fee from violating the season closure. Notice that, as described, the production function for effort can be expressed $e = kt$. This is a Cobb-Douglas function that is homogeneous of degree two, which represents very substantial scale economies. However, this is not considered a problem, for several reasons. First, the expansion of effort is constrained by $t \leq T$. The substantial economies up to the point $t = T$ suggest that fishermen will use the input "time" up to its maximum allowable amount T. Second, while there may be substantial economies in producing effort, the fisherman faces diminishing marginal returns to effort in the production of fish. Third, the expansion of effort is constrained by its cost, as described below. And fourth, this formulation is very descriptive of many fisheries.

$$e = e(k, t), \; \partial e/\partial k > 0, \; \partial e/\partial t > 0, \; t \leq T \qquad (1)$$
$$c = c(e(k, t)), \; dc/de > 0. \qquad (2)$$

For a given k, the maximum possible effort level is $e^*(k) = e(k, T)$. It is useful to further specify the cost function to incorporate the notion of constant short-run marginal cost. Subdivide total costs into "fixed" and "variable" components:

$$c = f(k) + v(k, t), \qquad (2')$$

where

$$df/dk > 0, \; \partial(v/e)/\partial k < 0, \; \partial v/\partial t > 0.$$

Fixed cost f represents the investment in vessel and gear which does not vary with the number of days they are employed during the season. Variable cost v represents the cost of operating a vessel during the fishing season. While fixed costs increase with the vessel's catching power, average variable and marginal costs of producing effort decline with increased capital intensity. Intuitively, larger vessels, or vessels equipped with gear that increases their ability to harvest fish, incur greater fixed cost but lower marginal cost per unit of effort.[6] Increasing the time spent fishing, on the other hand, does not affect fixed costs but does increase expenditures on variable cost components such as fuel, ice, and crew.

These cost relations are illustrated in Figures 2 and 3. Figure 2 displays total cost of effort curves for three levels of capital intensity, $k_0 < k_1 < k_2$. Fixed costs which increase in k are represented by higher vertical axis intercepts. Decreasing marginal costs of effort are represented by lower slope terms. Notice that the time constraint $t \leq T$ imposes a limit on the amount of effort a vessel can expend for a given k. Thus, each cost curve is truncated at its maximum level of effort, $e^*(k)$.

The associated short-run average and marginal cost curves are illustrated in Figure 3. Notice that, in each case, short-run average costs would continue to decline, except that the time limitation prohibits the fisherman from more fully "spreading out" her fixed cost over a larger amount of effort. Over some range (e.g., from k_0 to k_1), higher levels of k can be used to expand effort at lower average cost. But the time constraint becomes more binding for more capitalized vessels until, as with k_2, short-run average cost is never lower than it is for some other k.

"Long run" is typically used to denote the time horizon over which fixed costs can be adjusted. Adopt this convention and permit fishermen to adjust k between fishing seasons. Then, prior to a season, a fisherman faces a set of short-run cost relations as in Figure 3. The lower envelope of all short-run average cost curves represents the menu of long-run cost options. It is the long-run average cost curve illustrated by the dashed line in Figure 3. Thus, one obtains a long-run average cost curve with the familiar U-shape. Unlike Anderson, Visigilio, and Clark [1980], however, it is derived from a series of short-run curves, each of which is downward sloping.

Two Implications

The intent of this paper is to reconcile assumptions of "normal" looking cost of fishing effort curves with observations about real-world short-run fishing costs and the presence of regulatory control over the length of the fishing season in many fisheries. Its major implication is that a vessel's optimum capital intensity depends on the length of the fishing season. The model predicts that, *ceteris paribus*, optimum "plant size" is an increasing

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[6] It is important to again point out that "effort" is the (intermediate) output of the k and t inputs, and is measured in standardized units. Thus, it is possible that investment in k can increase total variable costs, but to avoid a degenerate case in which all vessels employ the minimum possible level of k, it must be assumed that average variable cost per unit effort decreases over some range of k. As drawn in Figures 2 and 3, marginal cost is constant for a given k, so $\partial v^2/\partial^2 t = 0$.

function of the length of the fishing season. This can be seen by reference to Figure 3. Reducing the length of the fishing season T causes each short-run curve to be truncated at lower effort levels. Since higher levels of k can now be utilized over a shorter fishing season, they lose some of their cost advantages. The effect is to decrease the effort level at which LRAC is minimized. In an open-access fishery comprised of homogeneous vessels, competition among vessels would force each one to operate at its minimum LRAC. Even if vessels are heterogeneous, the effects are the same: less capital intensive vessels become more cost effective. This is consistent with evidence that larger, capital intensive vessels do not earn the highest profits in some fisheries subject to frequent season closures.[7]

This leads to an implication about the political economy of fishing regulation. Stricter time constraints penalize more capital intensive vessels relatively heavily. If political sentiment lies with smaller operators, regulation through the control of the fishing season can be used to favor smaller vessels at the expense of larger vessels. This is consistent with the argument made in Karpoff, that many "traditional" forms of fishery regulation create wealth transfers among classes of fishermen. It is also consistent with the argument made by Morehouse and Rogers, who point to the fact that many of the regulatory controls used in the Alaska salmon fisheries have been designed to favor indigenous fishermen over "outsiders" who are typically more capitalized.

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[7] For example, the Alaska Commercial Fisheries Entry Commission has conducted extensive fiscal modeling of many Alaska fisheries at the individual vessel level, and reports that the largest and highest grossing vessels often do not have the highest net incomes. It appears that these vessels are overcapitalized. [Source: Kurt Schelle, Director of Research, Alaska Commercial Fisheries Entry Commission.]

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