Towards a Theory of the Regulated Fishery

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Abstract This paper develops a model of a modern regulated fishery in which direct biological controls such as gear restrictions and shortened seasons are used to control allowable harvest. Individual fishermen are assumed to make decisions regarding potential fishing and capacity in light of how they anticipate fellow fishermen and regulators to act. An equilibrium occurs in which there is excess capacity that is controlled at the fishery level to ensure aggregate harvest targets are not exceeded. Some discussion of alternative mechanisms such as direct limitations or taxes on potential effort and on individual fishermen is also presented.

A quick scan of the literature in fishery economics reveals that virtually no attention has been given to developing theories of microeconomic behavior that realistically capture the nature of the decision environment modern fishermen are faced with. This stands in particular contrast to the work being done in other fields of applied microeconomics, such as utilities regulation theory, where careful attempts have been made to capture the real-world working environment of industries. These latter studies have given applied microeconomic theory a degree of legitimacy in the last few years as several previously misunderstood real-world policy problems have been resolved with the aid of re-

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alistic theory and careful empirical research. The research findings have often led to better regulation policies as well as new sets of conceptual problems to look at.

Somewhat surprisingly, such theory-policy feedback has not taken place in fishery economics, even though it is sorely needed. In fact, only recently has much attention been paid to any new conceptual issues in the field. In the meantime, policy makers have increasingly found themselves struggling to patch up old and ineffective regulatory schemes or design new ones without being able to confidently predict the outcome of their policies. There is clearly a role for economists here, but it calls for a fairly major shift in emphasis away from normative modeling and towards predictive modeling. This paper discusses a tentative framework for such modeling that captures some of the important features of the regulatory structure in place in most modern fisheries.

Modern Fisheries—Some Stylized Facts

Economists have spent considerable effort on conceptual models of fisheries since World War II, and some important insights have been drawn. The most important results are probably those contrasting the nature of open access fisheries with various formulations of "optimally managed" fisheries. Unfortunately, however, beyond making the point that open access fisheries are potentially wasteful and threatening to species survival, we have not had much impact on real-world fishery management. To be fair, we have influenced the setting of fishery management *goals* in the larger sense, for example in directives under the Fishery Conservation and Management Act to manage for "socially optimal" stock levels rather than maximum sustained yields. In addition, economists' ideas about tradeable individual catch quotas, fishermen's cooperatives, and other efficiency-enhancing institutional changes are beginning to be talked about and gingerly experimented with at this point. On the whole, however, we have not helped much at the field level of fisheries, where these goals are (usually imperfectly) translated into specific policy *actions*.

This lack of field-level experience has in turn led to some incorrect understanding of how real-world fisheries actually operate.

Perhaps the most important difference between real-world fisheries and economists' (textbook) views of them is that the pure common-property open access model is no longer relevant. In the past, when the important world fisheries were high seas fisheries subject to no controls, it was valid to picture a process in which entry would occur until a bionomic equilibrium was reached. Today, however, most important fisheries have come under the jurisdiction of some nation and all are managed, mainly through traditional direct controls such as closed seasons and gear restrictions. They are managed first to ensure species survival, and second to produce an adequate (short-run) return to fishermen. The implication is that the view that fisheries will be driven to some low-level species equilibrium through entry is a faulty description of reality. In fact, most fisheries are managed to make sure that the stock does not fall below a certain openly targeted level (often the point of maximum sustainable yield). It is reasonable as a working hypothesis to propose, in fact, that management agencies will create instruments and controls necessary to make sure that targeted stocks (and corresponding allowable harvests) are maintained on average.

Within this context of a relatively fixed stock target, season-to-season management tasks are anything but simple. In essence, however, they generally boil down to an adversary situation in which the industry makes decisions about vessel designs and patterns of fishing behavior and the regulators use controls at their disposal to make sure that the application of such fishing capacity does not cause allowable harvest targets to be exceeded. In the real world, both species stock levels and the effectiveness of the application of effort are uncertain in varying degrees; regulators fine tune by monitoring catch, effort, and the like and then adjusting controls to achieve the goals. In fisheries where both species stock size and potential effort are uncertain and the species is particularly vulnerable, the fine tuning is very fine (e.g., 15-minute openings of the British Columbia herring fishery). In Pacific Coast salmon, fine tuning takes place week to week; in other fisheries controls are only adjusted yearly between seasons.

For the purposes of modeling real fisheries, the above observations indicate a need to look at the nature of the interaction between regulators and regulatees. At the aggregate level, regulators view their primary mandate as controlling the application of fishing effort by the industry (if necessary) in order to prevent overfishing, whereas the industry is collectively trying to circumvent the regulators and surpass the regulatory constraints in order to increase short-run profits. Industry behavior is not, of course, a result of carefully planned collective decisions, but is itself the outcome of gaming situations between the individual units at the microeconomic level. The mix of all of these interactions determines how an industry and regulatory structure will evolve. In the next section, a simple model of these interactions is developed.

A Model of the Regulated Fishery

Regulator-regulatee interaction may be formalized in a simple model of the fishery as follows. First consider the aggregate production function

$$H = F(X, K) \tag{1}$$

where X is the species stock size, K is a measure of aggregate industry fishing potential, and H is the aggregate harvest. We will assume that K is single-dimensioned, although in real fisheries K is in fact a function of several inputs that are not necessarily efficiently combined. Not much thought has been given to what form H should take and most studies simply borrow convenient forms from standard microeconomic theory. We will not have to be explicit other than to assume that $F(0, K) = 0 = F(X, 0)$. From Equation (1) above we can define the regulated production function:

$$H = F(\bar{X}, \theta K) \equiv f(\theta K) \qquad 0 \leq \theta \leq 1 \tag{2}$$

For a given exogenous or prechosen species stock size $\overline{X}$, a particular harvest objective H may be achieved by adjusting the regulation parameter θ to dampen potential effort K (chosen by the industry) to a level of "effective effort" θK. The parameter θ captures such things as shortened seasons, area closures, gear restrictions, and so on.

By fixing $H = \overline{H} = f(\theta K)$, the above formulation implicitly yields a feedback regulation function $\theta = \theta(K; \overline{H}, \overline{X})$ that establishes the level of θ that will allow exactly H to be harvested with potential effort K. Such an instantaneous adjustment policy represents the extreme in controllability, of course, although several regulated fisheries probably are relatively close. In other fisheries θ must be set in advance and hence X and K must be estimated to arrive at a preset θ. Whether or not H is actually achieved as a result depends on how accurate forecasts of X, K, and f are.

The level of aggregate potential effort that must be monitored (and perhaps regulated by setting $\theta < 1$) is determined by the fishing industry as a whole. The industry is composed of many individual decision-making units, of course, and hence the sum of their individual decisions results in the particular level of K. Let us assume that there are N members of the industry and each must decide how much potential effort to apply to the fishery. Let k_i be the amount chosen by the ith member, r the rental price of a unit of potential capacity, and $P = 1$ the price per unit of fish caught. Then the ith vessel owner sees profits π to be

$$\Pi_i = \frac{k_i}{\Sigma^N k_j} f(\theta \Sigma k_j) - rk_i \tag{3}$$

The anticipated profit formulation in Equation (3) reflects the assumption that each vessel owner realizes the nature of the interactions between himself or herself, the regulators, and the other fishermen. The profits are contingent on what the remaining $N - 1$ fishermen choose as their levels of k_j as well as what level θ is chosen by the regulatory authority. Since each views the problem in a similar way, we have, in effect, a noncooperative N-person game that determines the outcome.

To solve the problem, let us assume that each vessel owner makes a forecast of the other fishermen's potential capacity $(N - 1)\hat{k}$. Assume also that regulators are able to employ instantaneous policy adjustment to fix $f(\theta K) = \overline{H}$. Then the optimal level of k_i for our representative fisherman is found by differentiating Equation (3) and setting it equal to zero:

$$\frac{d\Pi_i}{dk_i} = \frac{f[k_i + (N - 1)\hat{k}] - k_i f}{[k_i + (N - 1)\hat{k}]^2} - r = 0 \tag{4}$$

Remember that f is fixed and equal to $\overline{H}$, and that total anticipated potential effort $\Sigma k_j = k_i + (N - 1)\hat{k}$. Thus the optimal level of k_i for our representative fisherman is

$$k_i^* = \sqrt{\frac{(N - 1)\hat{k}f}{r}} - (N - 1)\hat{k} \tag{5}$$

The level of k_i in Equation (5) is not necessarily an equilibrium choice, since it depends on $\hat{k}$, which may or may not turn out *ex post* to be a correct anticipation. We can define an expectations equilibrium (or Nash equilibrium) to be one in which each individual fisherman forecasts $\hat{k}$ and chooses k_i^*, which then turns out to be the same $\hat{k}$ predicted by the other fishermen in their choices. Thus in an expectations equilibrium $k_i^* = \hat{k}$. In the general case, we can rewrite Equation (5) to yield

$$\frac{k_i^*}{\hat{k}} = 1 + \left[\sqrt{\frac{(N - 1)f}{r\hat{k}}} - N\right] \tag{6}$$

Thus our representative fisherman will attempt to build a bigger boat than rival fishermen as long as

$$\sqrt{\frac{(N - 1)f}{r\hat{k}}} - N > 0 \quad \text{or} \quad \frac{f}{N\hat{k}} > r\frac{N}{N - 1} \tag{7}$$

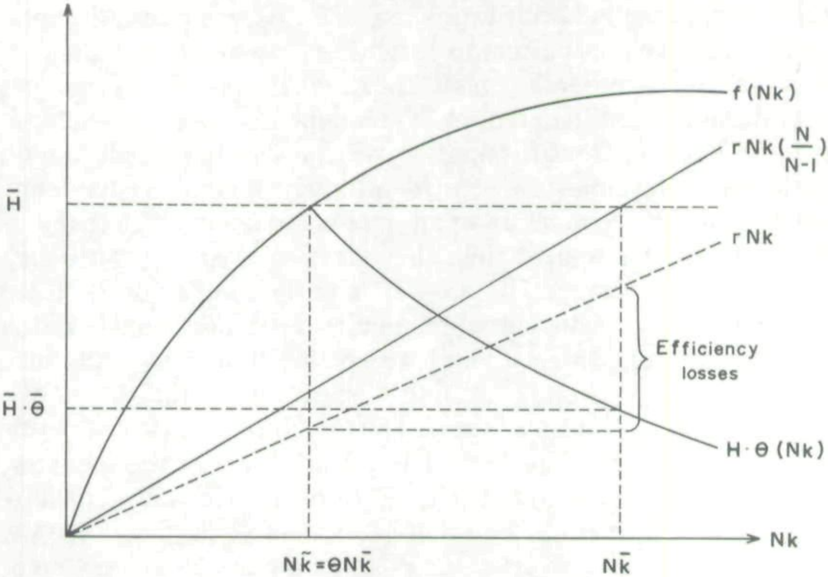

FIGURE 1. Efficient and regulated equilibrium levels.

or when the rivals' forecasted revenues per vessel are greater than costs $r\hat{k}$ by the factor $N/(N - 1)$. An equilibrium $k_i^* = \bar{k}$, the expectations or Nash equilibrium, is reached where

$$\frac{f}{N\bar{k}} = r\left[\frac{N}{N - 1}\right] \tag{8}$$

At that point each vessel is still making a positive (but small for large N) profit equal to $r\bar{k}/(N - 1)$ and the industry's total profits are $r\bar{k}[N/(N - 1)]$. Figure 1 shows the regulated industry equilibrium as modeled above. Suppose that regulators desire that the total harvest be $\bar{H}$. The most efficient way to harvest would be to set $\theta = 1$ and allow only $N\tilde{k}$ units of effort. But from Equation (7) above, we know that an expectations equilibrium will not be sustained at that point since $f/N\tilde{k} > r[N/(N - 1)]$. Thus each vessel owner will apply more effort, and θ will have to be set at lower values to keep $f(\theta Nk) = \bar{H}$.[1] An equilibrium is reached where potential effort has expanded to $N\bar{k}$ and effective effort actually applied to $N\tilde{k} = \overline{\theta}N\overline{k}$. At this point, the total cost of using excess effort to catch $\overline{H}$ is as shown above.

As the above model suggests, there will be a tendency towards rent dissipation, the extent of which depends upon how large N is. For large N, rent dissipation will be nearly complete with large efficiency losses where f/r is large.[2] Given the tendency toward inefficiency and dissipation of profits, and given that participants should realize this, the question arises of why such behavior takes place. The answer is fairly simple. By de facto fixing of the aggregate catch, regulators force individual decision makers to focus on relative shares of the total rent. But since the shares sum to one, one unit's share loss is the rest of the industry's gain and vice versa. Thus each unit must always be making a strategic decision relative to the rest of the industry. Unfortunately, however, disequilibrium decisions, which look strategically best from the point of view of each unit, have the effect of worsening everyone's position when actually enacted. This situation is encountered in other group behavior instances and is basically a variant of the Prisoners' Dilemma problem. This can be seen by supposing that we begin with all N participants selecting an effort level $\tilde{k} \leq k_0 < \overline{k}$, that is, a disequilibrium k_0 more efficient than the equilibrium k. Now suppose that our representative fisherman contemplates increasing potential efforts to $k_0 < k^* \leq \overline{k}$. Figure 2 shows the pay-off matrix; each cell shows by how much profits would increase if the rest of the industry made a similar adjustment or stayed at k_0. Although it is not readily obvious by inspection, it can be shown that whenever the industry is out of equilibrium ($k_0 < \overline{k}$), the best individual strategy is to increase effort to k^* regardless of which strategy is anticipated by one's rivals. Thus if one believes that the industry will maintain a level $(N - 1)k_0 < (N - 1)\overline{k}$, then the right column of the matrix yields the relevant payoffs and the top right box will be strictly positive when $k_0 < \overline{k}$. If it is believed that the industry will adjust to a larger $k_0 < k^* < \overline{k}$, then the left column is relevant and losses will be minimized by also increasing k to k^*. Thus irrespective of whether one expects rivals to follow, it always seems best to increase k above any initial level k_0 when $k_0 < \overline{k}$, even when k_0 is the rent maximizing level k^*.

		REST OF THE INDUSTRY	
$\Delta \pi_i$		increase effort to k^*	maintain effort to k_o
FIRM i	increase effort to k^*	$-rN\left[\sqrt{k_o\bar{k}} - k_o\right]$	$\sqrt{k_o\bar{k}}\left[f\left(\frac{N-1}{N}\right)\frac{1}{\sqrt{k_o\bar{k}}} - rN\right]$
	maintain effort at k_o	$\frac{f}{N}\left\{\frac{1}{1+(N-1)\left[\frac{\sqrt{k_o\bar{k}}}{k_o}-1\right]}-1\right\}$	0

FIGURE 2. Payoff matrix for changes in level of effort for Firm *i*.

The prisoner's dilemma paradox is that such seemingly rational individual behavior leads to a collective outcome where everyone is worse off.

To summarize this section, the model presented here captures two essential types of interactive behavior present in most regulated fisheries. The reaction of the regulatory authority to the prevailing level of potential aggregate effort is incorporated and assumed perfect in the sense that θ is adjusted instantly and accurately to ensure the targeted harvest level is not exceeded. Individual decision makers in the industry are assumed to make decisions regarding how much effort to employ by taking account of behavior of other rival fishermen as well as that of the regulatory agency. Their collective decisions result in a common property equilibrium that dissipates potential rents to a greater or lesser degree depending upon how large N is.

The approach taken here differs from the traditional literature in fishery economics in that the stock level is not a result of open access entry but is determined exogenously. In addition, the extent of rent dissipation depends upon the number of participants in the industry and the nature of strategic rivalrous behavior among them. In fisheries with few participants, this recognition of their mutual interdependence leads to a relatively larger rent equilibrium. As N gets large the situation approaches a more traditional pure competition, full-dissipation equilibrium. The model thus raises a new question—what determines whether N is large or small in various fisheries?

One simple way to look at this issue is to note that N defines the number of fishing "firms" in a fleet. A fishing firm requires an entrepreneur, of course, and also incurs set-up costs to enter an industry. In fishing, these set-up costs may be substantial; for example, a person must spend time and forgo income learning about the waters, the habits of the fish, the gear, the weather, and so on in order to even begin catching fish. Let us denote the annualized value of such fixed costs FC to be C ($= \rho FC$ where ρ is the interest rate). Suppose also that the potential entrepreneur in question can earn Π per year outside of the fishing industry. Then, for an industry already composed of N vessels, it will pay our representative potential entrepreneur to become a participant fisherman (create a new fishing "firm") as long as

$$\frac{f}{N} - r\bar{k} - C = \frac{r\bar{k}}{N-1} - C > \Pi \tag{9}$$

or as long as revenues less capital and set-up costs exceed opportunity costs. An industry equilibrium of both $\bar{k}$ and N is reached when

$$f - r\bar{k}N = \frac{r\bar{k}N}{N-1} = N(\Pi + C) \tag{10}$$

Let $J(\bar{k}, N)$ represent the function in the middle of Equation (10). As N increases, J changes according to

$$\frac{dJ}{dN} = \frac{-f}{N^2} < 0 \tag{11}$$

(remembering that $\bar{k}$ is a function of N). Thus as N increases, J falls, while the right-hand side increases, ensuring a finite-sized industry equilibrium, $N = \overline{N}$.[3] The characteristics of this equilibrium are obvious from Equation (10) and provide some interesting testable hypotheses. For example, one result the model suggests is that localized inshore fisheries (e.g., lobster) will tend to attract participants who are primarily local. For these individuals, the start-up costs will be lower than for outsiders because of specialized local knowledge (perhaps passed down through generations) of the species' behavior, weather, seas, and the like. If other local employment opportunities are limited the effect is reinforced and further rent dissipation would be expected. High seas fisheries, in contrast (e.g., halibut), would tend to be less localized, other things being equal, because we would expect high start-up costs and few insider advantages. One might also expect that technological developments such as electronic sounders or fish finders would act to reduce localized advantage and hence the fleet would become more mobile and less local—or perhaps two fleets could exist simultaneously. In any case, the model retains the flavor of traditional rent dissipation ideas and yet allows the possibility of more efficient fisheries in which one can say that, in an important sense, the existence of significant rents is a return to specialized skills that provide an entry barrier in an otherwise open access industry.

Regulation by Incentive Mechanisms

It is likely that economists and biologists would judge the success of a direct control regulatory scheme such as that modeled in the preceding section by substantially different criteria. Biologists might point to the relative ease of administration and the acceptability to fishermen of effort dampening types of regulations as strong points. Their principal measure of success would probably be how close the actual regulations came to targeted harvest rates. Recommendations for improvements in the regulatory design would thus be directed towards better methods of stock and fishing capacity measurement as well as better methods of on-line fine tuning.[4] Economists, on the other hand, would look at economic efficiency—the cost of harvesting the specific targeted harvest rate—and would largely judge this scheme a failure on those grounds.

From the standpoint of efficiency, the problem with potential-effort dampening regulations is that they are ineffective instruments with which to tackle failures of the incentive system. In this case, although the species is protected, fishermen are led to compete with each other for larger shares of the (fixed) allowable catch. Thus there is a tendency to overinvest in potential fishing capacity to either achieve an edge over one's rivals or to keep up with one's rivals. Overall, of course, everyone faces the same incentives, and when aggregate catch is fixed, such investments simply dissipate rents and cause further tightening of regulations, which negate the new capacity. Thus from an economist's point of view, a more fruitful way to design regulatory schemes would be to somehow impose the proper incentive schemes on individual decision makers to cause them to behave as if they were cost minimizers. Several schemes have been proposed and will be examined below.

Potential-Effort License

One scheme that has been particularly discussed by economists is a licensing scheme whereby participants must purchase licenses to apply given amounts of effort. Serious practical problems exist in real-world cases, however, because potential effort is difficult to measure and hence to tax. For our simplified model, where potential effort is measured by k, it is easy to see how such a scheme should work ideally. Let p represent the price of a license to apply a unit of k. Then each fisherman will try to maximize the modified profit function

$$\Pi_i = \frac{k_i}{k_i + (N - 1)\hat{k}} f - (r + p)k_i \tag{12}$$

A Nash equilibrium is reached when

$$\frac{f(\theta N k^*)}{N k^*} = (r + p)\frac{N}{N - 1} \tag{13}$$

which defines the number of licenses that the industry will demand at price p per unit effort. Suppose that regulatory authorities allocate an aggregate total of Nk licenses to the industry. Since the license market must equilibrate, p will adjust until the demand specified in Equation (13) equals the allotted supply or until $p = p^e$, where:

$$p^e = \frac{N - 1}{N} \frac{f}{Nk} - r \tag{14}$$

and where Nk is the (fixed) allotted supply. Let $\overline{N}k$ be the open access equilibrium level of aggregate industry potential effort. Suppose that $Nk < \overline{N}k$ licenses are allotted or a buy-back scheme is used to reduce the supply previously allotted. From Equation 14 above, it is obvious that with Nk licenses allotted, the market clearing price depends on how large N is. But N is determined by profitability in the fishing industry relative to outside opportunities. With a licensing scheme, industry profits would be

$$\begin{aligned} f - Nk(r + p) &= Nk \frac{1}{N - 1}(r + p) \\ &= \frac{Nk}{N - 1} r + \frac{Nk}{N - 1} \frac{N - 1}{N} \frac{f}{Nk} - r = \frac{f}{N} \end{aligned} \tag{15}$$

and hence the equilibrium number of participants would adjust to satisfy

$$\frac{f}{N} = N(\Pi + C) \qquad N = \sqrt{\frac{f}{\Pi + C}} = \overline{N} \tag{16}$$

which is the same number as in the regulated open access case in Equation (10). Thus an allotment reduction becomes absorbed wholly through reductions in potential effort per vessel k rather than numbers of participants. As the allotment approaches the efficient effort level $N\tilde{k}$, the price of licenses rises to $\tilde{p}^e$. At less restrictive allotments it will be necessary to adjust θ to keep $f(\theta NK) = \overline{H}$. In fact, the equilibrium license price can be expressed as a function of either the ratio of efficient to allotted aggregate effort or the ratio of unregulated equilibrium effort to allotted effort:

$$p^e = \tilde{p}^e \frac{\tilde{N}k}{Nk} + r\left(\frac{\tilde{N}k}{Nk} - 1\right) = (\tilde{p}^e + r)\theta - r$$
$$= r\left(\frac{\overline{N}k}{Nk} - 1\right) \qquad (17)$$

which varies inversely with the allotment Nk between $\tilde{p}^e$ (for $Nk = \tilde{N}k$ and $\theta = 1$) and zero (when $\overline{Nk} = Nk$ and $\theta = \tilde{k}/\overline{k}$). This expression also allows us a convenient form for aggregate industry rents that would accrue to the grantor (e.g., the government if an auction is held) or the original holders (if licenses were allotted free and reduced by buy-back or attrition), namely

$$p^e Nk = rNk\frac{\overline{N}k}{Nk} - 1 = r(\overline{N}k - Nk) \qquad (18)$$

where $\overline{N}k \geq Nk$. Thus an effort-directed licensing scheme will not improve the welfare of individual fishermen over the unlicensed situation. Profits accruing to each fisherman-entrepreneur will be the same regardless of how many licenses are allotted, since license prices rise to absorb rents as they accrue as Nk is reduced.

Participation License

Another qualitatively different method for potential effort reduction is to license the entrepreneur or fisherman-owner rather than aggregate vessel capacity. Alaska has done this in its salmon limitation program and in British Columbia the herring fishery is regulated similarly. From the point of view of the individual fisherman, a fixed cost associated with staying in the industry should have no impact on the marginal capacity decision as determined by Equation (8), given that N is fixed. However, since k is a function of N and since by Equation (10) a lower N will increase equilibrium profits per vessel, pressure to enter the industry will drive the price of participation licenses up to a positive level whenever $N < \overline{N}$ where $\overline{N}$ satisfies $rk(\overline{N})/(\overline{N} - 1) = \Pi + C$ in Equation (10). In fact, with sufficient competition, the market clearing price of N licenses to participate will eliminate any above-normal advantage to being in the industry, that is:

$$p_N = \frac{rk(N)}{N - 1} - (\Pi + C) \tag{19}$$

a function of N bounded from below by 0 (when $N = \overline{N}$) and above by $\tilde{p}_N$ (when $N = \tilde{N}$, the efficient number of participants). With this price, each participant's profits will be

$$\begin{aligned} \frac{f}{N} - rk - p_N &= \frac{f}{N} - rk\left(1 + \frac{1}{N - 1}\right) + \Pi + C \\ &= \frac{f}{N} - rk\frac{N}{N - 1} + \Pi + C \end{aligned} \tag{20}$$

for any chosen k and a given number $N \leq \overline{N}$ of licenses. But for a given N, by Equation (8) above, the optimally chosen k is such that the first two terms on the right-hand side sum to zero and hence profits are $\Pi + C$, which is independent of k and N. These profits, moreover, are by Equation (10) the (regulated) open access profit level; hence a participation licensing scheme will (like an effort license scheme) leave fishermen's incomes absolutely unchanged. Prices will simply rise to confer rents on original holders or the grantor depending upon how such licenses are transferred. Overall, there will be fewer participants, each employing vessels that have more potential fishing capacity than without participation licenses.

Effort Tax

Another often-proposed mechanism is a tax on a vessel's potential capacity or effort potential. This scheme would work exactly like the aggregate effort license scheme, except that authorities would have to calculate a tax rate instead of an allotment of licenses. This can be seen by noting that an effort tax on the vessel affects profits in the same way as a license price, and hence the Nash equilibrium for a vessel tax t_v is

$$\frac{f(\theta Nk^*)}{Nk^*} = (r + t_v)\frac{N}{N-1} \tag{21}$$

as in Equation 13 above. The optimal (efficiency-producing) tax rate is defined by

$$\tilde{t}_v = \frac{N-1}{N}\frac{f}{N\tilde{k}} - r \tag{22}$$

Simply by increasing t_v to $\tilde{t}_v$, authorities may force vessel owners to employ the efficient amount of capital. At rates below $\tilde{t}_v$, the tax policy must also be supplemented with an effort-dampening policy in order to maintain the selected harvest rate. It also is true that in this case the number of participants will equilibrate at the level shown in Equation (16) and profits will be $f/\overline{N}^2$ regardless of what the tax rate is, as in previous examples.

Fish Tax

A landing tax t_f that leaves fishermen with a net value of $1 - t_f$ per fish, alters the fishermen's perceived profits shown in Equation (3) by multiplying f by $1 - t_f$. Thus the new Nash equilibrium is where

$$\frac{f(\theta Nk^*)}{Nk^*} = \frac{N}{N-1}\frac{r}{1-t_f} \tag{23}$$

Hence a landing tax works exactly like a vessel tax or license charge increase, since when t_f rises, $r/(1 - t_f)$ also rises. The optimal $\tilde{t}_f$ is defined as

$$\tilde{t}_f = 1 - \frac{N}{N-1}\frac{rN\tilde{k}}{f} \tag{24}$$

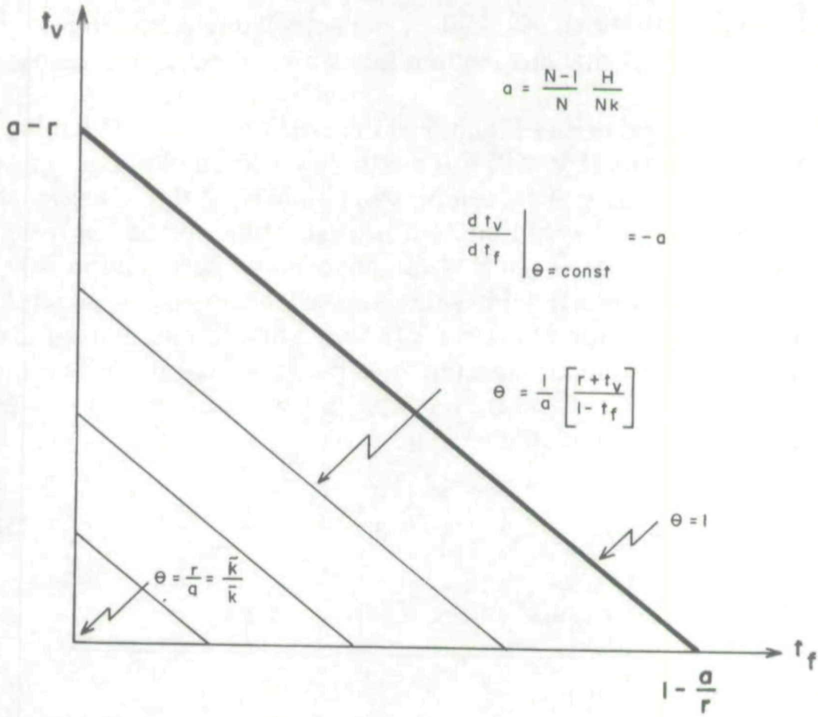

FIGURE 3. Direct regulation and tax policy options in a regulated fishery.

Again, setting $t_f < \tilde{t}_f$ will require additional effort control, which can be achieved by using θ.

Combined Policies

From the above, it should be apparent that in this simple model any of the above instruments can be employed to achieve efficiency alone or in concert with any of the others. It may be administratively more desirable, for example, to have moderate taxes on both the vessel and the landings than one heavy tax on either alone. Or it may be desirable to sacrifice some efficiency by setting $\theta < 1$ and then using some lower combination of taxes to achieve a second-best efficiency level. The diagram in Figure 3 delineates, as an example, the combination of policy parameters that might be used and their impacts, if one were interested in combining effort and landing taxes and direct effort restrictions.

The darkened line in Figure 3 is the efficiency locus of landing and vessel taxes that will force fishermen to employ cost-minimizing levels of k. Tax combinations inside of the locus must be supported with additional effort-restricting policies in order to reach the desired harvest target levels. The equation $\theta = (1/a)[(r + t_v)/(1 - t_f)]$ defines the level of θ necessary, in general, for any combination of tax rates (t_v, t_f). For combinations of tax rates not on the locus, of course, efficiency losses must be incurred, since $\theta < 1$ implies extra (and wasted) capacity. The losses may be calculated as

$$rN\,[\bar{k} - (\tilde{k}/\theta)] = rN\left(\bar{k} - \tilde{k}a\,\frac{1 - t_v}{r + t_v}\right) \tag{25}$$

where $t_f \leq 1 - r/a$ and $t_v \leq a - r$.

Summary

The model of a regulated fishery introduced above is a first approximation of a theory in which fishing industry behavior is aggregated from a microeconomic-level theory of the individual unit's behavior. Particular attention has been paid to incorporating several important features of real-world regulated fisheries. At the macroeconomic level, it has been assumed that regulatory agencies target aggregate harvest levels and employ nonselective measures to control aggregate effort such as shortened seasons, area closures, and the like in order to meet the targets. At the microeconomic level it has been assumed that individual units take regulatory agency behavior as given (and completely effective) and make investment decisions based on expectations of fellow fishermen's decisions. Thus the equilibrium concept is one of a Nash equilibrium for an N-person noncooperative game. The characteristics of the equilibrium are slightly different from traditional fishery literature, since some positive rents can be earned in equilibrium, although the amount is small for fisheries with many participants.

In the section on incentive mechanisms we examine the impact on such a regulated industry of additional controls designed to improve economic efficiency. Two quantitative controls—aggregate effort licensing and participation licensing—and two pricing controls—effort taxes and landing taxes—are examined. Results in this simple one-input case are all similar; namely, the fishermen's welfare remains unaltered but efficiency is improved as controls are made more stringent. In all but one scheme the impact is to leave participation unchanged and affect the amount of investment of potential effort per participant. Some results showing how efficiency and traditional effort-control policy parameters may be combined to achieve different levels of efficiency are also derived.

There are several extensions of this simple model that are being developed to present in future papers. The most important is an extension from a single- to a multiple-input effort production technology. In real multiple-input fisheries, traditional controls have potentially complex impacts on choice of fishing technology and on actual fishing behavior, a point that becomes obvious when we contrast, for example, how a reduction in season length would be responded to by fishermen compared with a gear restriction. The second extension is an examination of disequilibrium mechanisms. It is important for policy purposes, for example, whether the participation rate responds faster than the per-firm effort potential or vice versa when price goes up. Whichever is true will determine what types of policy instruments are most appropriate and the specific mechanism will dictate at what levels policy parameters should be set. Finally, the model needs to be amended to account for uncertainty and the inability of regulatory agencies (and/or the regulatees) to forecast and measure perfectly and respond instantly. All of these factors are important in varying degrees in real fisheries and hence should be examined for a better understanding of regulated fisheries.

Notes

1. Since $\overline{H} = f(\theta N k)$ defines θ, we have $\theta = [f^{-1}(\overline{H})]/Nk$. But $\theta = 1$ at $\overline{H} = f(N\tilde{k})$, so that $N\tilde{k} = f^{-1}(\overline{H})$. Thus $\theta = \tilde{k}/k$ defines the optimal regulatory function graphed in Figure 1.

2. As N is small, on the other hand, the gap between efficient inputs and those chosen by Nash competitors narrows with the possibility that for N sufficiently small, the efficient input level would be chosen.

3. In this case, per vessel profits at the equilibrium values of $\bar{k}$ and $\bar{N}$ turn out to be $f/N^2 = \Pi + C$, implying $N = \sqrt{[f/(\Pi + C)]}$. Thus the open-access number of firms can be considered fixed and determined exogenously if the response of numbers of participants is rapid. A more complete approach would include some dynamics of adjustment of participants and of effort response of participants.

4. Such as disaggregating overall quotas into gear-type quotas to permit easier control of a fleet consisting of vessels of differing effectiveness.