FISHERIES ENFORCEMENT WHEN AVOIDANCE IS POSSIBLE
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ABSTRACT
When fishers can avoid detection and/or sanctions for violating fisheries management rules, the fisheries enforcement problem becomes substantially more complicated. A number of issues immediately pop up. First, the effectiveness of enforcement effort is reduced. This, ceteris paribus, reduces the optimal enforcement effort. Second, the impact on the fishery of increasing enforcement effort or penalties for violations is no longer clear cut. When fishers can take steps to avoid detection or sanctions, it is possible that the relationship between the level of violations and the level of penalties or enforcement effort is reversed; i.e. higher penalties lead to more violations and vice versa. The third issue relates to the net social benefits obtainable from a fishery under these circumstances. Is it possible that most or all of the potential fisheries rents may be dissipated by the cost of increased avoidance activity?

This paper deals with these issues. It constructs a simple model of the enforcement problem under avoidance and attempts, on that basis, to provide partial answers to the questions raised above.

Keywords: Fisheries enforcement, enforcement under avoidance, avoidance, fisheries management

INTRODUCTION
In basic enforcement theory [1],[2], the enforcement activity increases the probability of having to pay a penalty for a violation. In many, perhaps most, situations, violators do not have to take this probability as exogenous. They can undertake various actions to reduce it. We refer to these actions as avoidance.

Avoidance actions may be broadly grouped to two classes; (i) measures to avoid detection and (ii) measures to avoid having to pay the (full) penalty if detected. In fisheries there are many ways to avoid detection involving the timing, location and extent of illegal activities. Sometimes special equipment can be used for this purpose as well. Measures to avoid paying the (full) penalty when detected include legal defence, negotiations and bribes.

Avoidance activity is generally costly — if it were not it would always be run at the maximum level. Thus avoidance is like a production process. The gain or output is a reduction in the expected penalty cost to the business. This, however, can only be obtained at a cost, the cost of avoidance. The possibility of avoidance activity greatly complicates the theory of enforcement, especially that of optimal enforcement. In what follows this will be explored.

THE BASIC THEORY OF FISHERIES ENFORCEMENT

In the basic theory of fisheries enforcement [2], fishers faced with the enforcement of harvest restrictions will try to solve the following problem:

$$\max_{q} B(q,x) - \pi(e) \cdot f \cdot q,$$

s.t. $q \geq 0.$

(P)
In this expression, \( q \) is the quantity of illegal harvest, \( x \) biomass, \( e \) enforcement effort and \( f \) the unit penalty. The function \( B(.,.) \) is the benefit function to fishers and the function \( \pi(.,.) \) is the probability of having to pay the penalty. The function \( B(.,.) \) is assumed to be monotonically increasing in biomass and in harvest up to a point. The function \( \pi(.,.) \) is assumed to be monotonically increasing. Both functions are taken to be concave.

Solving this private problem yields the necessary condition:

\[
B_q(q,x) - \pi(e) \cdot f = 0.
\]

This necessary condition gives rise to the enforcement response function:

\[
q = Q(e, f, x),
\]

which is declining in \( e \) and \( f \) and increasing in \( x \), provided illegal fishing takes place at all.

The social problem is to set enforcement effort to solve the following:

\[
\begin{align*}
\text{Max}_{q} & \int_{0}^{\infty} [B(q,x) - C(e)] \cdot e^{-rt} dt, \\
\text{s.t.} & \quad \dot{x} = G(x) - Q(e, f, x), \\
& \quad e \geq 0.
\end{align*}
\]

In this problem, the function \( C(e) \) is the enforcement cost function which is assumed to be increasing and at least weakly convex in \( e \). \( G(.,) \) is the natural biomass growth function. \( r \) represents the rate of time discount and \( t \) time.

Solving the social problem, \( (S) \), leads to the following socially optimal enforcement rule:

\[
(B_q(q,x) - \lambda) \cdot Q(e, f, x) = C_e(e), \text{ all } t \text{ when } e>0,
\]

where \( \lambda \) represents the shadow value of biomass. Note that the conventional dynamic optimality rule is \( B_q(q,x) = \lambda \) at all \( t \) (see e.g. [3]). The social optimality rule expressed in (2) thus makes it clear that the conventional rule is wrong when enforcement costs are taken into account. In fact, since according to our assumptions, \( Q_e<0 \), the socially optimal rule is that \( B_q(q,x) < \lambda \). In other words, for any level of biomass and shadow value of resource, the socially optimal harvest when enforcement is costly is greater than the optimal harvest calculated on the basis of zero harvesting costs.

This establishes our first main result:

Result 1

When fisheries enforcement is costly, socially optimal harvest exceeds the level specified by the traditional rule, \( B_q(q,x) = \lambda \).

An obvious corollary to Result 1 is that the optimal enforcement effort is less than that corresponding to the traditional rule.

It is possible to express the solution to the optimal enforcement problem, i.e. the rule expressed in equation (2), graphically in an informative manner. Figure 1 illustrates the solution in terms of enforcement effort.
In Figure 1, the downward sloping curve is the net marginal benefits of enforcement defined as \((B_q(q,x) - \lambda)\cdot Q(e,f,x)\) in expression (2) above. As can be seen from Figure 1, the fact that enforcement is costly reduces the optimal enforcement effort compared to the alternative. Obviously, if enforcement were costly enough, the optimal level of enforcement would be zero.

Figure 2 tells essentially the same story in terms of harvest. In interpreting the figure note that algebraically the ratio

\[
\frac{C_i}{Q_i} = \frac{\partial C(e)/\partial e}{\partial Q(e,f,x)/\partial e}
\]

is equivalent to the derivative \(C_q\). According to the diagram, if enforcement were costless, i.e. \(C_q = 0\) for all \(q\), the traditional optimal harvest rule, \(B_q(q,x) = \lambda\), would apply. However, with costly enforcement, enforcement is reduced and harvest increased. The open access harvest level is at the point where the marginal benefit curve intersects with the horizontal axis, \(B_q = 0\). For that point to be socially optimal, the marginal costs of enforcing a harvest restriction must be very high as suggested by the diagram.

**AVOIDANCE ACTIVITY**

Let us now consider the possibility of avoidance. In that case the probability of having to pay a penalty function becomes

\[
\pi(e,u),
\]

where, \(u\) represents avoidance activity and \(e\) is enforcement effort as before. We take it for granted that \(\pi(e,u)\) is increasing in \(e\) and declining in \(u\). If that wasn’t the case neither activity would ever be undertaken. Since probabilities cannot be negative, we assume that \(\pi_{ue} > 0\). It seems reasonable also to assume that \(\pi_{ee} \leq 0\). Note that this means that while the function \(\pi(\ldots)\) is concave in \(e\) and convex in \(u\), it is neither convex nor concave in the two variables jointly. This can potentially cause difficulties in maximization.

There is of course an economic cost associated with avoidance activity. Let that be represented by the increasing and weakly convex cost function.
Under these circumstances the fishers are faced with the following maximization problem:

\[
\max_{q,u} B(q, x) - \pi(e, u) \cdot f \cdot q - CA(u),
\]
\[
\text{s.t. } q, u \geq 0.
\]

The necessary conditions are:

\[
B_q(q, x) - \pi(e, u) \cdot f = 0,
\]
\[
-\pi_u(e, u) \cdot f - CA_u(u) = 0.
\]

The resulting solutions for harvest and avoidance activity may be expressed as:

\[
Q(e, f, x),
\]
\[
U(e, f, x).
\]

Without further restrictions on the functions, the sign of the first derivatives of these functions cannot be determined (see appendix). Thus, with avoidance activities possible, it does not have to be the case that increased enforcement or higher fines lead to lower illegal harvests. The reason is that it is possible that increased enforcement effort leads to increased avoidance which more than counteracts the increased enforcement effort. The following A simple example may serve to make this more clear.

**An example**

Consider a avoidance technology consisting of two options \( u = 0 \) and \( u = \overline{u} \). Let the \( \overline{u} \) be perfectly effective so if \( \overline{u} \) is employed the probability of penalty is zero. In other words, \( \pi(e, \overline{u}) = 0 \) for all \( e \).

Let the cost of \( \overline{u} \) be \( CA(\overline{u}) \). To make the problem interesting, we assume that \( B(q(e, \overline{u}), x) - CA(\overline{u}) > 0 \). The cost of \( u = 0 \) is \( CA(0) = 0 \).

Now, as discussed above, if the fisher, employs \( u = 0 \), his optimal harvest is \( Q(e, 0; f, x) \). (Note that \( Q(e, 0; f, x) \) is simply our previous harvest function \( Q(e, f, x) \) conditional on \( u = 0 \) being chosen). If on the other hand he employs \( u = \overline{u} \), his optimal harvest is \( Q(e, \overline{u}; f, x) \). Clearly, for any positive enforcement activity \( Q(e, \overline{u}; f, x) > Q(e, 0; f, x) \).

As specified above, for any given enforcement activity and biomass level, the net benefits to the fisher of any avoidance strategy is:

\[
V(u) = B(Q(e, u), x) - \pi(e, u) \cdot f \cdot Q(e, u) - CA(u).
\]

Thus, the net benefits of the two avoidance options in our example are:

\[
V(0) = B(Q(e, 0), x) - \pi(e, 0) \cdot f \cdot Q(e, 0),
\]
\[
V(\overline{u}) = B(q(e, \overline{u}), x) - CA(\overline{u}).
\]
Comparing these two should make it clear that there exist in general some levels of enforcement effort, \( e \) and avoidance cost, \( CA(u) \) such that \( V(\bar{u}) > V(0) \); just let the avoidance cost approach zero. Similarly there exist in general some levels of enforcement effort, \( e \) and avoidance cost, \( CA(\bar{u}) \) such that \( V(\bar{u}) < V(0) \); just let the avoidance cost be high enough.

More formally consider the difference

\[
\Delta(e, \bar{u}) = V(e, \bar{u}) - V(e, 0) = B(q(e, \bar{u}), x) - CA(\bar{u}) - (B(Q(e, 0), x) - \pi(e, 0) \cdot f \cdot Q(e, 0)).
\]

This function is clearly (i) continuous in \( e \), (ii) negative for \( e = 0 \) and (iii) positive for sufficiently high \( e \), provided that \( CA(\bar{u}) \) is not too high and (iv) monotonically increasing in enforcement effort. The last assertion follows immediately from differentiating the difference, \( \Delta \), with respect to \( e \).

\[
\frac{\partial \Delta}{\partial e} = -\left(B_q(Q(e, 0) - \pi(e, 0) \cdot f \cdot q) \cdot Q_e(e, 0) + \pi_e(e, 0) \cdot f \cdot Q(e, 0)\right).
\]

The first term on the rhs is zero by the optimality condition (1). Thus, \( \frac{\partial \Delta}{\partial e} > 0 \).

These observations regarding the difference, \( \Delta \), prove that increasing enforcement effort may lead to more violations.

This example is somewhat contrived in that the avoidance activity is discrete. However, it is possible to construct examples of the same thing with continuous avoidance activity. However, at least in the examples I have constructed, the algebra becomes messy.

It is important to realize that while for some levels of enforcement, increased enforcement effort may lead to less compliance due to the avoidance response, it would never make any sense for the enforcement agency to operate at these levels. Thus, this perverse response can only be observed when the enforcement agency is operating sub-optimally. Whether that makes the empirical observation of the perverse response less likely is another matter.

THE ENFORCEMENT PROBLEM UNDER AVOIDANCE

The enforcement problem under avoidance is to solve the following:

\[
\text{Max} \int_0^\infty [B(Q(e, f, x), x) - CA(U(e, f, x)) - C(e)] \cdot e^{-\tau t} dt \\
\text{s.t. } \dot{x} = G(x) - Q(e, f, x), \\
e \geq 0.
\]

This problem differs from the enforcement problem when there is no avoidance, i.e. problem (S), only in that the cost of avoidance, \( CA(u) \) is subtracted from social benefits.

A necessary condition for solving (SS) is:

\[
(B_q - \dot{\lambda}) \cdot Q_e + CA_u \cdot U_e, \text{ all } t, \text{ provided } e > 0.
\]

Comparing this result with the one without avoidance, i.e. (2), shows that the possibility of avoidance adds a term to the rhs of the necessary condition. This term reflects the marginal cost of privately optimal avoidance when enforcement effort is increased. This as we have seen may be either positive or negative — the sign of \( U_e \) is indeterminate. However, most likely it will be positive. So, taking that
for granted, one may say that the mathematically formal effect of avoidance is equivalent to an increased cost of enforcement. This will obviously lead to less optimal enforcement.

For comparative purposes, it may be helpful to illustrate this impact in the same way as in Figures 1 and 2 above. Figure 3 shows the impact of avoidance on the optimal enforcement effort level. As illustrated, avoidance reduces the optimal enforcement effort even further than costly enforcement does. Note that since the enforcement effort is assumed to be optimal the derivative $U_e$ must be positive.

Figure 3 also provides certain information about the net social gains from the fishery. Basically these gains are measured by the area between the gross marginal benefit curve, $\frac{\partial(B(q,x) - \lambda \cdot q)}{\partial e}$, and the relevant cost curves. As the curves are drawn in Figure 3, these net social gains under costly enforcement and avoidance are in the neighbourhood of $1/3$ of the net gains obtainable with costless enforcement and no avoidance.

Figure 4 conveys essentially the same information in the space of harvest volume. As indicated, the possibility of costly avoidance makes reigning in of harvests less socially beneficial than before. Indeed, the diagram makes it clear that if the induced enforcement cost of avoidance is high enough, the open access harvest level will also be socially optimal. I.e. any enforcement effort will not be optimal.

As in Figure 3, Figure 4 can be used to judge the social loss due to (i) costly enforcement and (ii) costly avoidance.

Needless to say the dynamic optimal paths under avoidance can be worked out as in [4].

The above analysis can be summarized in the following result:

**Result 2**

When avoidance activities are privately optimal, the optimal harvest exceeds the level specified by the traditional rule even more than when fisheries enforcement is merely costly.
DISCUSSION

In fisheries enforcement as in the enforcement of other socially beneficial rules, there is a social cost associated with (i) the cost of enforcement and (ii) the cost of avoidance. The first cost may be seen as a reluctance to abide by the rules. If fisheries followed the published rules without the threat of a penalty, the cost of enforcing them would disappear. The second cost is more like a systematic attempt at breaking the rules without running the risk of a penalty. Both represent lawlessness. The former can be labelled passive lawlessness, the latter active lawlessness.

Assuming that the enforcement is socially optimal, both types of lawlessness represent an economic loss. The loss of active lawlessness, i.e. avoidance activities, is even greater when the incentives to develop better avoidance techniques and invest in them are taken into account. The economic aim is to maximize the net benefits of the fishing taking all associated costs into account. Thus, from an economic perspective, there is no material difference between the costs of enforcements and the costs of avoidance. From a social perspective, on the other hand, it may be particularly disturbing when what amounts to a new industry develops just to reduce the probability of a penalty.

Avoidance activities are socially costly just as overfishing is. Overfishing is dealt with by imposing and enforcing restrictions. It appears logical, therefore, to impose restrictions on avoidance activities (zero level seems to be optimal) and enforce that restriction. How that would be done in practice is another matter.

REFERENCES


APPENDIX

INVESTIGATING THE RELATIONSHIP BETWEEN ENFORCEMENT EFFORT AND HARVESTS AND AVOIDANCE

Profit maximization by fishers generates the necessary conditions (see main text):

\[ B(q,x) - \pi(e,u) \cdot f = 0, \]
\[ -\pi_u(e,u) \cdot f \cdot q - CA_u(u) = 0, \]

where \( q \) is harvest, \( x \) biomass, \( e \) enforcement effort, \( u \) avoidance activity and \( f \) the level of fines. The function \( B(q,x) \) is the private benefit function, \( \pi(e,u) \) the probability of penalty function and \( CA(u) \) the cost of avoidance.

Total differential of this system yields the matrix equation:
\[
\begin{pmatrix}
B_{pq} & -\pi_u \cdot f \\
-\pi_u \cdot f & -(\pi_{uu} \cdot f \cdot q + CA_{uu})
\end{pmatrix}
\begin{pmatrix}
dq \\
du
\end{pmatrix}
= \begin{pmatrix}
\pi_e \cdot f & \pi \\
\pi_{we} \cdot f \cdot q & \pi_u \cdot q
\end{pmatrix}
\begin{pmatrix}
de \\
df
\end{pmatrix}
\]

which may be written more concisely as:

\[A \cdot x = B \cdot y.\]

Since (1) and (2) represent profit maximization, the determinant of \(A, \det A\), must be positive.

Interesting partial derivatives include

\[
\frac{\partial q}{\partial e} = \frac{-\pi_e \cdot f \cdot (\pi_{uu} \cdot f \cdot q + CA_{uu}) + \pi_u \cdot \pi_{we} \cdot f^2 \cdot q}{\det A},
\]

\[
\frac{\partial q}{\partial f} = \frac{-\pi \cdot (\pi_{uu} \cdot f \cdot q + CA_{uu}) + \pi_u^2 \cdot q \cdot f}{\det A},
\]

\[
\frac{\partial u}{\partial e} = \frac{B_{pq} \cdot \pi_{we} \cdot f \cdot q + \pi_u \cdot \pi_e \cdot f^2}{\det A},
\]

\[
\frac{\partial u}{\partial f} = \frac{B_{qu} \cdot \pi_u \cdot q + \pi_u \cdot \pi \cdot f}{\det A}.
\]

It is easy to verify that none of these partial derivatives can be readily signed without imposing quantitative restrictions on the signs of the derivatives involved. Exploring further, it turns out that

\[
\frac{\partial q}{\partial e} \leq 0, \text{ if } \frac{\pi_u}{\pi_{uu}} \geq \frac{\pi_e}{\pi_{we}}.
\]

So, at least for this partial derivative, the shape of the probability of penalty function and in particular its response to avoidance and enforcement effort is crucial. Thus, since \(\pi_{we} < 0\), this condition will be satisfied if \(\pi_u = 0\) or sufficiently close to zero. If, however, \(|\pi_e|\) is sufficiently high, i.e. avoidance is sufficiently effective in reducing the probability of having to pay a penalty, then the partial derivative \(\frac{\partial q}{\partial e} > 0\), i.e. increased enforcement effort leads to more violations not less.