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FISH FARMING IN COMPETITION WITH AN OPEN-ACCESS FISHERY

by

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1. Introduction

A competitive industry, which overuses a common-access resource, may create a barrier to entry similar to Spence's example of a cartel that uses excess capacity to prevent entry. In most industries, when a new firm enters, existing firms find that their demand curves have fallen so they reduce their output to "accommodate" the new entrant. In Spence's model, the cartel disintegrates upon entry so that the output of existing firms increases which may make entry unprofitable.

In an open-access fishery, the supply curve bends backward. Thus, a fall in price created by the entry of a fish farm increases rather than decreases supply in the backward-bending portion of the supply curve. An important implication of this theory is that fish farms are more likely to be unprofitable the more heavily overharvested is a species in a common-property, competitive market. This natural barrier to entry may explain why true mariculture is "barely in its infancy" (Bardach, Ryther, and McLarney).

2. The Basic Model

A fishery's open-access competitive equilibrium is determined by four equations (see, e.g., Smith). First, the fish stock, X, is in steady-state equilibrium such that the increase in fish stock, $\dot{X}$, equals zero:

$$\dot{X} = f(X) - hK = 0, \tag{1}$$

where f(X) are the natural net births (births minus natural deaths), K is the number of fishing boats, h is the harvest per boat, and hK is the total catch.

Second, boats enter the market until profits per boat are zero:

$$ph - C(X, h) = 0 \tag{2}$$

where p is the price of fish, ph are the revenues per boat, and $C(X, h)$ is each boat's cost function which depends on the stock of fish and catch per boat (where partial derivatives C_X and C_{hX} are negative and C_h and C_{hh} are positive).

Third, each boat equates the marginal cost of catching fish with the price of fish

$$C_h(X, h) - p = 0. \quad (3)$$

Fourth, the market demand, $Q(p)$, equals the supply from the natural fishery, hK, plus that from fish farms, $q(p, \theta)$, where θ is a shift parameter reflecting technological change or growth of fish farms (so q_θ is positive):

$$Q(p) - q(p, \theta) - hK = 0. \quad (4)$$

If we impose the usual stability condition that the derived demand in the open-access fishery, $Q(p) - q(p, \theta)$, must cut supply from above, then it is easy to show that $dp/d\theta$ is negative, $dX/d\theta$ is positive, and $d(hK)/d\theta = dS/d\theta$ has the same sign as f_X. The negative sign of $dp/d\theta$ shows that increased entry of a competitor causes price to fall. This result is not surprising--even a competitive model would have that property. What is unusual here is that, in the range where f_X is negative [where supply is backward sloping], as θ increases, the supply from the open-access fishery increases[1] (Williamson suggests the failure of oligopolists to accommodate entry indicates predatory behavior).

Where the supply from the open-access fishery increases in response to growth of fish farms, price falls more precipitously than it would if the open-access fishery accommodated entry.[2] The more that price will fall after the entry of a fish farmer, the less likely is the potential farmer to enter if he has rational expectations.

3. An Example: A Schaefer Model

To illustrate these general static results and other dynamic possibilities, we examine the simple dynamic Schaefer model of an open-access fishery described by Smith rewriting (1) as

$$\dot{X} = (\alpha - \beta X)X - hK. \qquad (1')$$

Let $C(X, h) = \gamma h^2/X + I$ be the cost of harvesting at rate h when the fish stock is X where γ is a parameter and I is the fixed cost (or opportunity value of the boat in another fishery). Each boat then chooses its harvest rate to maximize profits by choosing h so that price equals marginal cost which implies that equation (3) may be written as

$$h = \frac{pX}{2\gamma} \; . \qquad (3')$$

The entrance of a fish farmer shifts the derived demand curve facing the open-access fishery inward. For instance, suppose the supply curve for fish farming is $q = np$, where n is the number of fish farms (n corresponds to θ above). If market demand is $p = u - vT$, where T (total quantity) is $q + hK$, then the derived demand facing the commons is the market demand less the supply from the fish farm:

$$p = \frac{u}{1 + vn} - \frac{v}{1 + vn} hK = d - ehK. \qquad (5)$$

Solving equation (3') and equation (5) for the harvest per boat as a function of X and K yields $h = dX/(2\gamma + eKX)$. Substituting this expression for h into equation (1') gives

$$\dot{X} = (\alpha - \beta X)X - \frac{dXK}{2\gamma + eKX} \qquad (6)$$

which describes the evolution of the fish stock as a function of X and K alone. Rewriting the $\dot{X} = 0$ equation, we know that, in a long-run steady state, the open-access fishery supplies $S = hK = (\alpha - \beta X)X$.

In an open-access fishery, boats enter until the marginal boat earns zero profits or price equals average cost [equation (2)]:

$$p = \frac{\gamma h}{X} + \frac{I}{h} = 2\sqrt{\frac{\gamma I}{X}}. \tag{7}$$

We can use equation (8) to eliminate X from (7) so that we can write the supply curve as

$$S = \left(\alpha - 4\beta I \frac{\gamma^2}{p}\right) 4I \frac{\gamma^2}{p}. \tag{8}$$

This curve is shown in Figure 1. The open-access supply curve is backward bending which illustrates the possibility of overharvesting. The heavy straight line in Figure 1 is the market demand curve (in the absence of a fish farm). The light straight line shows the residual demand curve after a fish farm enters. Differentiating equation (8) shows that higher prices are always associated with smaller fish stocks.

If the initial equilibrium is at E_1 where there is overfishing, the entry of a fish farm can cause the equilibrium to shift to F_1 where there is a larger catch, a lower price, and a larger stock of fish. There is, of course, a more dramatic possibility: the fish farm could cause a shift to F_3.

4. A Dynamic Analysis

The Schaefer example presented in Section 3 can be used to analyze the dynamic adjustment which results from the entry of a fish farm into the market. Following Smith (but see Berck and Perloff), we assume that the rate of entry is proportional to instantaneous profits. For simplicity, we follow that practice here. Profits per boat are

$$(d - ehK)\, h - \frac{\gamma h^2}{X - I}; \tag{9}$$

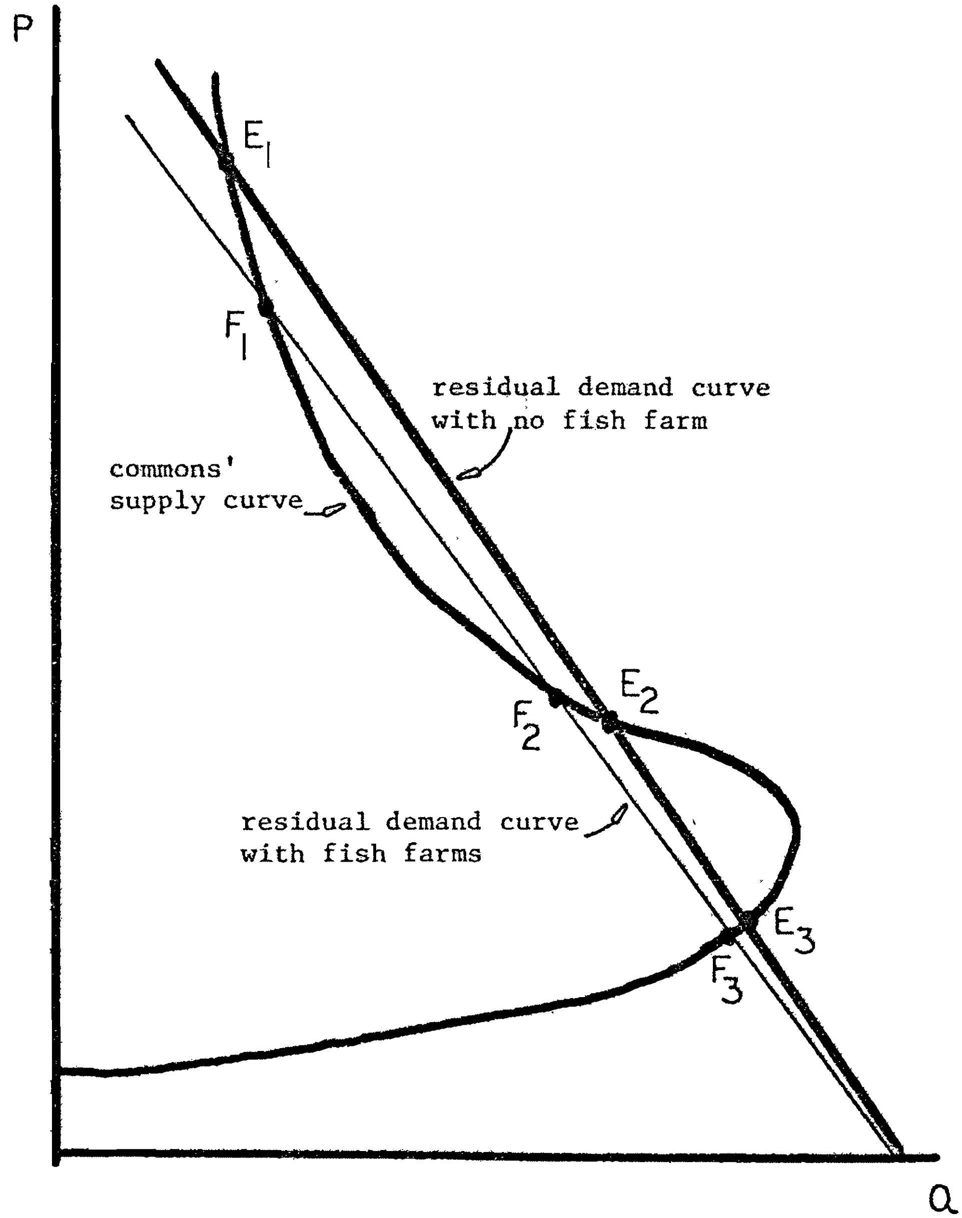
P
E1
F1
residual demand curve
with no fish farm
commons'
supply curve
E2
F2
residual demand curve
with fish farms
E3
F3
Q

FIGURE 1

so, if the constant of proportionality is δ, then the evolution of the stock of boats is

$$\dot{K} = \delta\left[\frac{d^2X}{2\gamma + eKX} - \frac{(eK + \gamma/X)\, d^2X^2}{(2\gamma + eKX)^2} - I\right]. \tag{10}$$

Equations (10) and (11) characterize the open-access fishery.

The equilibria of the open-access fishery are determined by the intersections of the curves $\dot{X} = 0$ and $\dot{K} = 0$ as shown (by the heavy lines) in (X, K) phase space in Figure 2. Let $K = G(X, d, e)$ solve $\dot{X} = 0$. Setting $\dot{X} = 0$ from (6) gives $G(X, d, e) = 2\gamma(\alpha - \beta X)/(\beta eX^2 - \alpha eX + d)$. The K intercept is found by evaluating $G(0, d, e)$, which is $2\gamma\alpha/d$, and the X intercept is found by solving $G(X, d, e) = 0$ for X which is α/β. Taking the derivative of G with respect to X shows there is at most one critical point in the strictly positive orthant.

Similarly, we can solve $\dot{K} = 0$ [equation (11)] for K: $H(X, d, e) = (d\sqrt{\gamma IX} - 2\gamma I)/(eIX)$. Setting $K = H(X, d, e) = 0$ gives the X intercept, $4I\gamma/d^2$. Setting the differential with respect to X equal to zero reveals a single relevant critical point. Taking the limit of H as X approaches infinity shows that the curve becomes asymptotic to the X axis. Thus, $\dot{X} = 0$ and $\dot{K} = 0$ in Figure 2 are as drawn, and there are at most three equilibria (see Smith for the single equilibrium case).

Entrance of the fish farmer shifts the $\dot{X} = 0$ curve upward and the $\dot{K} = 0$ curve downward as shown (by the light lines) in Figure 2. Substituting for d and e into H(X, d, e) gives $H^*(X, n) = (u\sqrt{\gamma IX} - 2v\gamma Inp - 2\gamma I)/(vIX)$. Since the derivative of H(X, d, e), $D_nH^* = -2v\gamma Ip/(vIX)$, is negative, the $\dot{K} = 0$ locus shifts inward when fish farms enter. Similarly, substituting into G(X, d, e) gives $G^*(X, n) = [2\alpha\gamma + 2\alpha v\gamma np - (2\beta v\gamma np + 2\beta\gamma)\, X]/(\beta vX^2 - \alpha vX + u)$. Its derivative is $D_nG^* = 2v\gamma p(\alpha - \beta X)/(\beta vX^2 - \alpha vX + u)$ which

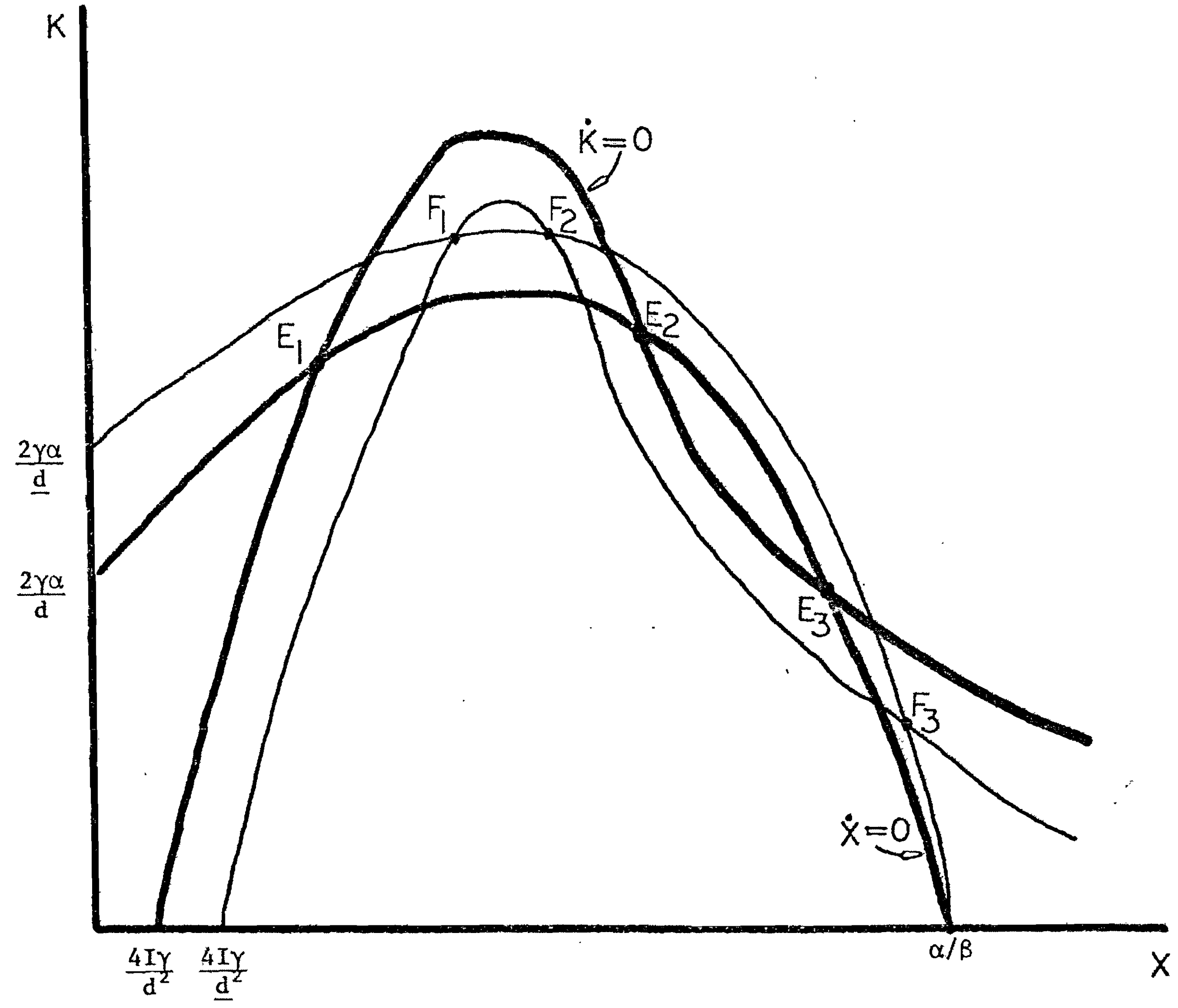
K
$\dot{K}=0$
F_1
F_2
E_1
E_2
E_3
F_3
$\dot{X}=0$
$\frac{2\gamma\alpha}{d}$
$\frac{2\gamma\alpha}{d}$
$\frac{4I\gamma}{d^2}$
$\frac{4I\gamma}{d^2}$
α/β
X

FIGURE 2

is positive for fish stocks less than the natural carrying capacity, α/β, which are the only relevant fish stocks. Therefore, the $\dot{X} = 0$ locus shifts up with fish farm entry.

The possibility of a large shift is illustrated in the phase space diagram, Figure 2 (where the arrows correspond to the high lines). As the figure shows, if the original equilibrium was at E_1, the new equilibrium could be at either F_1 or F_3. The new equilibrium certainly will be F_3 if the entry of the fish farm leads to a single equilibrium such as when the light demand curve in Figure 1 swings down so far that it only intersects the supply curve once on the upward-sloping section of the supply curve. Similarly, $\dot{X} = 0$ could rise and the $\dot{K} = 0$ fall by enough that there is only one equilibrium at F_3.

When entry moves the equilibrium from E_1 to F_3, the open-access fishery's output increases greatly and the price falls precipitously. Thus, if the fish farm has large fixed costs (heretofore ignored), this drop could easily drive it out of business.

The previous discussion illustrates how the entry of a fish farm can increase output in a competitive industry where there is overharvesting; that is, we showed how the entry of the fish farm could lead to a shift from equilibrium E_1 to F_1 or possibly to F_3. Perversely, it appears possible (a phase diagram can be drawn with the property) that, if the initial equilibrium were at E_3 (i.e., output can only be increased by increasing fishing effort), the entry of a fish farm could cause the equilibrium to shift to F_1. In this case the commons would start overharvesting after the fish farm entered. For this outcome to occur, E_3 must have a higher level of K than occurs at F_2.

5. Welfare Implications

From society's viewpoint, the change from the low-stock to the high-stock equilibrium will involve a lower price for the product and an increased catch which increases the welfare of consumers; but it may also cause short-run losses for existing fishing vessels which will, of course, exit the fishery.

Whether the gainers could compensate the losers depends on the interest rate and other parameters. This shift will definitely be welfare improving if the interest rate is close to zero (the future matters as much as the present) or if the costs of shifting a boat from this open-access market to another fishery are low.

Since fish farms reduce overharvesting in the open-access fishery but the owners of the farms do not capture this social benefit, there will be a tendency to undersupply fish farms so government subsidy may be socially desirable. Unfortunately, fish farms cannot lead to a first-best equilibrium in the open-access fishery since the commons problem continues. Thus, the best the government can hope to accomplish by encouraging fish farming is to reduce the overfishing problem, not eliminate it.

If the government tried to encourage fish farming by transferring property rights, such as the sole right to fish a certain river or stream, there would be two effects: The removal of fishing grounds from the open-access fishery shifts the $\dot{X} = 0$ equation downward and the entry of competition from the newly created fish farm. Thus, the effects are reinforcing and the analysis is as before: Using a natural habitat to encourage fish farming can drive an open-access fishery from a point such as E_1 (extreme overfishing) to a point such as F_3 (less overfishing).

Footnotes

[1]The supply of fish from the natural resource fishery is $S = hK$. Totally differentiating this equation and (1), (2), and (3) shows that $dS/dp = hf_X/C_X$. That is, as price rises, the supply increases (decreases) if the sign of f_X is negative (positive). Alternatively stated, supply is backward bending where f_X is negative.

[2]The response of price to growth of fish farms is $dp/(d\theta) = -q_\theta/[dS/dp - (Q_p - q_p]$. If dS/dp is positive (supply is backward bending) or zero, $dp/d\theta$ is less negative than if dS/dp were negative.

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