Pricing Strategies for a Renewable Resource Industry Faced with Competing New Technology: The Case of Aquaculture and the Commercial Fishery

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Abstract: Technological change in the form of aquaculture is becoming an important factor in the market for several species of fish. In the light of those changes, producers in some ocean-based fisheries need to evaluate their production and pricing strategies relative to their emerging competitor—aquaculture. This paper conceptually analyzes the optimal pricing and production strategy for an ocean-based fishery facing a decreasing lagged demand resulting from the entry of competitive aquaculturalists. The optimal strategy consists of initially raising the price to a maximum level to earn some fast profits, taking advantage of the lagged decline in net demand. After the demand declines and natural fish stocks are reduced such that the singular arc is reached, price is adjusted downward to maintain the singular arc approach to the long-run equilibrium. In the long run, price will be lower, natural fish stocks higher, and natural fish supply either lower or higher depending on the initial position of the system and the magnitude of the net demand shift.

Introduction

Aquaculture (as defined by Bardach *et al.*, 1972) is beginning to have a profound impact on the market structure of and international trade in several seafood products. In many ways, the changes that are occurring are much like those that occurred as society developed from hunting and gathering to agriculture. In other ways, the transition is vastly different.

Today's ocean-based fishing industry is analogous to the hunter society in terms of the harvest. The fish harvest depends on underlying fish population dynamics, numbers of competing fishermen, and environmental factors that result in uncertain harvest per unit of fishing activity. On the other hand, the market structure and institutional mechanisms that influence the fishing industry are different from primitive societies. Today, essentially all fisheries are under some sort of regulatory mechanisms aimed primarily at reducing the problems associated with open access to a common property resource. Also, both regulatory and resource ownership factors have resulted in a seafood industry that ranges from decentralized, competitive markets (i.e., New England groundfish) to markets that are characterized as vertically integrated (i.e., New England red crab).

Aquaculture has become (or is becoming) an important factor in the market for species such as catfish (USA), trout (USA, Norway, and France), various species of Pacific salmon (Japan, USA, and potentially Chile), Atlantic salmon (Norway, UK, and potentially USA and Canada) and shrimp (Asia and Ecuador). The rate at which aquaculture has become significant is often surprising. For example, production of pen-reared Atlantic salmon from the dominant supplier (Norway) has increased from 98 t in 1971 to 23,320 t in 1984, and projected production is 80,000 t by 1990. Pen-reared Atlantic salmon worldwide are projected to reach 96,000 t by 1990. World aquacultural production of shrimp is also expected to continue to rapidly increase; the 1982 level was 78,000 t, and shrimp production is projected to reach 240,000 t by 1990 (Aquaculture Project Group, 1984).

In the light of those changes, members of some ocean based fishing industries need to evaluate their long-term position *vis-à-vis* the aquaculture industry. One important consideration is the pricing and production strategy for the ocean based fishing industry faced with increased competition from aquacultural suppliers that results in decreased net demand for ocean caught fish. Recent research (Aquaculture Project Group, 1984) indicates that decreasing net demand for ocean caught shrimp could occur in the shrimp market. Under current institutional conditions, the projected increase in shrimp consumption is less than the projected increase in aquacultured shrimp supply, leading to a decrease in projected net shrimp demand. Similar conditions may exist in the salmon markets in the not too distant future.

Dynamics of a Pricing Strategy for Fishermen

We assume that long-run net demand for the fishery as a result of aquacultural supply is linear and negatively sloped and that adjustment to the long-run demand is given by the differential equation:

$$(1)\ \ Y = \delta Y/\delta t = \alpha(-Y+a-bp)\ ,$$

where Y is net fish demand, p is price, and α, a, and b are parameters. We further assume that the commercial fishery is solely owned or cooperatively managed to maximize discounted profit, and the growth curve for the renewable fish resource is described by the commonly used (Clark, 1976) differential equation:

$$(2)\ \ x = \delta x/\delta y = f(x) - Y = rx[1-(x/K)] - Y\ ,$$

where x is ocean fish stock, r is the intrinsic growth rate, and K is the environmental carrying capacity.

The fishermen's problem is to choose a price to maximize discounted profits (P):

$$(3)\ \ Max\ P\ {}_0\!\int^{\infty} e^{-\delta t}[p-c(x)]Y\,dt\ ,$$

subject to equations *(1)* and *(2)*, and

$$p_{min} \leq p \leq p_{max}\ ,\ x \geq 0\ ,\ \text{and}\ Y \in [0, \infty]\ ,$$

where δ is the discount rate and $c(x)$ is the unit cost of harvest $(c' \leq 0)$.

The Hamiltonian of the fishermen's problem is:

$$(4)\ \ H = e^{-\delta t}[p-c(x)]Y + \theta_1\alpha(-Y+a-bp) + \theta_2[f(x)-Y]\ .$$

The necessary conditions for optimization are:

$$(5)\ \ -\theta^{\bullet}_1 = \delta H/\delta Y = e^{\delta t}[p-c(x)] - \theta_1\alpha - \theta_2\ ,$$

$$(6)\ \ -\theta^{\bullet}_2 = \delta H/\delta x = e^{\delta t}c'Y + \theta_2 f'\ ,$$

$$(7)\ \ \delta H/\delta p = e^{\delta t}Y - \theta_1\alpha b\ ,$$

equations *(1)* and *(2)*, and the transversality conditions,

$$\theta_1(\infty)Y(\infty) = 0\ ,\ \text{and}\ \theta_2(\infty)x(\infty) = 0\ .$$

The first observation is that the problem is linear in the control, p, which implies that the solution will be the "bang-bang" type (Miller, 1979). Therefore, the optimal value of p will be p_{min}, p_{max}, or, on the singular arc, p^*. From equation *(7)*,

$$(8a)\ \ e^{\delta t}Y > \theta_1\alpha b \Rightarrow p_{max}\ ,$$

$$(8b)\ \ e^{\delta t}Y = \theta_1\alpha b \Rightarrow \text{singular arc}, p^*, \text{and}$$

$$(8c)\ \ e^{\delta t}Y < \theta_1\alpha b \Rightarrow p_{min}\ .$$

Making the appropriate manipulations on the necessary conditions results in the singular arc equation for p^*,

$$(9)\ \ \{(\delta-f')[-c(x)+(a/b)]+c'f(x)\}/(2\alpha+\delta) - [(\delta-f')Y]/\alpha b + (a-Y)/b = p^*\ .$$

Substituting for p in Y yields:

$$(10)\ \ Y^{\bullet} = \{-\alpha b(\delta-f')[-c(x)+(a/b)]-c'f(x)\}/(2\alpha+\delta) + (\delta-f')Y\ .$$

Equations *(2)* and *(10)* create a system of differential equations that has stationary points (x and Y equal to zero) defined by:

$$(11)\ \delta = f' - [c'f(x)]/\{(a/b)-Y[(2\alpha+\delta)/\alpha b]-c(x)\}\ .$$

Multiple equilibria may obtain in this system. A similar situation is shown in Clark (1976). However, the present analysis is based on the assumption of a single equilibrium.

A path for price that is on the singular path defined by equation *(9)* and that also satisfies the transversality conditions,

$$lim(t\rightarrow\infty)\ e^{\delta t}Y^2/\alpha b = 0 \text{ and}$$

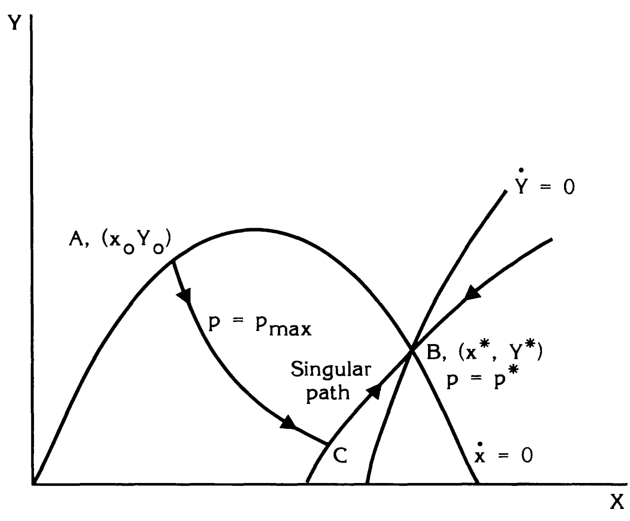
$$lim(t\rightarrow\infty)\ e^{\delta t}\{(a/b)-c(x)-Y[(2\alpha+\delta)/\alpha b]\}x = 0\ ,$$

is on where *lim Y* and *lim x* are constant at time infinity. That implies that the optimal path to the time infinity equilibrium is on the separatrix. The problem then becomes how to get to the separatrix. The state Y and x cannot be adjusted instantly to the separatrix.

Since the control problem is linear, the most rapid approach path from the initial position is required. That will give rise to either a maximum price or minimum price approach to the singular path. Assume that before aquacultural supply starts, price is p_o, the initial fish stock x_o, and the initial harvest Y_o, as indicated by point A in Figure 1. As aquaculturalists increase supply, lagged net demand decreases. When the natural fishery is faced with decreasing net demand, the new long-run equilibrium is given by point B for an optimally managed fishery. That equilibrium is found by solving the system of equations *(2)* and *(10)* when $\dot{x}$ and $\dot{Y}$ are equal to zero. Point B will always result in a larger fish stock than an equilibrium such as point A when there was no aquacultural supply. That has been shown elsewhere (Anderson, 1983).

The problem remains to find the optimal approach to point B from the initial point A. First, the fishermen must set a price such that the singular arc is most rapidly reached. That is achieved by setting price at p_{max} until point C on the singular path is attained. Then the control is switched from p_{max} to p^* until point B is reached in time infinity.

Figure 1—Solution of Decreasing Lagged Demand Model



The above solution has some intuitive appeal. Since the fishermen realize that the long-run net demand will be less than it is initially, they naturally would want to get what they can while they can. Because the demand response is not instantaneous, the fishermen have time to make some fast profits. The intuitive strategy would be to charge the highest price institutionally possible, selling in each instant just the amount that will maintain the price and not violate the population harvest dynamics. At some point, however, demand will have adjusted sufficiently and the population stock will be high enough to encourage fishermen to decrease price in such a way that the price, harvest, and fish stock will be maintained on the singular path to the long-run equilibrium. On the singular path, net demand increases, driving out the "excess" aquaculturalists.

Decreasing demand does not imply that the new equilibrium harvest will necessarily be smaller than the initial solution, assuming that the initial solution was optimal for the original demand situation. It is easy to imagine a fishery with a very high demand resulting in a low stock, low harvest, and high price at equilibrium. When the situation changes with the entry of aquaculture, a new, lower long-run net demand may result in higher stock, higher harvest, and lower prices at equilibrium.

Conclusion

This paper presents an analysis of optimal fishery management under a dynamic demand that is characterized by lagged adjustment. The optimal policy consists of setting the control at an extreme until the singular arc is reached. On the singular arc, the control is adjusted in each instant such that a stable long-run equilibrium is asymptotically approached.

The case of dynamic demand that is declining may occur where the long-run demand to the fishery is the long-run net demand resulting from the entry of an aquaculturalist who produces the same product. The demand dynamic is created by the lagged adjustment of the aquaculturalists to their long-run supply. In the case of declining demand, the optimal policy consists of initially raising price (the control) to the maximum level to take advantage of the lagged decline. That could be characterized as a "get-it-while-you-can" strategy. After the demand declines and natural fish stocks are reduced such that the singular arc is reached, price is adjusted downwards to maintain the singular arc approach to the long-run equilibrium. In the long-run, price will be lower, natural fish stocks higher, and natural fish supply either lower or higher depending on the initial position of the system and the magnitude of the demand shift.

Note

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