BIOECONOMIC MODEL OF A FISHERY

Now we are going to develop and analyze a model for the economics of fishing. Anderson (1986), on the Recommended Reading list, provides a brief overview of basic economic theory and terminology and covers much of the material shown below.

For simplicity we will use the Graham-Schaefer model for the biological dynamics, but any of the surplus-production models could be used instead. Start with the logistic model for latent productivity (natural biomass growth) and examine a fishery at equilibrium.

$$G(B) = r \cdot B \left(1 - \frac{B}{K}\right)$$

At equilibrium removals by the fishery are just balanced by the latent productivity of the stock.

$$G(B) = Y(B) = q \cdot f \cdot B \quad B \text{ and } f \text{ represent equilibrium values.}$$

$$r \cdot B \left(1 - \frac{B}{K}\right) = q \cdot f \cdot B \quad \Rightarrow \quad Y(f) = K \cdot q \cdot f \left(1 - \frac{q \cdot f}{r}\right)$$

We derived this relationship in an earlier lecture.

You may recall that the growth curve $G(B)$ has slope $r$ at the origin. The equilibrium yield is zero if $(q \cdot f)$ is greater than $r$.

To proceed with our economic analysis we need to transform yield in biomass to yield in money. If, for simplicity, we assume that the price for one unit of fish biomass is constant $p$, then the long-run equilibrium relationship between the total revenue from the fishery and the size of the fishing fleet $f$ is a parabola, reflecting the shape of the growth curve.

$$TR(f) = p \cdot Y(f)$$

$$TR(f) = p \cdot K \cdot q \cdot f \left(1 - \frac{q \cdot f}{r}\right)$$

The $TR(f)$ curve is identical to the $Y(f)$ curve but with a different vertical scale.
The **average revenue** (averaged with respect to fishing effort) is

\[ AR(f) = \frac{TR(f)}{f} = p \cdot K \cdot q \left(1 - \frac{q \cdot f}{r}\right) \]

The AR(f) curve represents the gross earnings per unit of effort.

The **marginal revenue** (marginal with respect to fishing effort) is

\[ MR(f) = \frac{d}{df} TR(f) \]

\[ MR(f) = p \cdot K \cdot q \left(1 - 2 \cdot \frac{q \cdot f}{r}\right) \]

The maximum total revenue occurs where the marginal revenue is zero (where the slope of TR(f) is zero).

If the marginal revenue is negative, it means that adding another unit (here, a unit of effort) reduces the total revenue.

Now we will add costs to the model. Assume that the fishing fleet consists of \( f \) identical vessels and that each one incurs costs \( c \) to operate per unit time period.

The **total cost** of maintaining and operating the fleet is \( TC = c \cdot f \).
The average cost is

$$\text{AC} = \frac{\text{TC}(f)}{f} = c.$$  

And the marginal cost is

$$\text{MC} = \frac{d\text{TC}(f)}{df} = c.$$  

We can plot the revenue and cost functions on the same axes.

Economic equilibrium will occur at that level of fishing effort at which all supernormal profits are dissipated. This occurs at that level of effort for which AR=AC. This equilibrium is usually described as the open access equilibrium (oae). In the graphs the effort level that generates the open access equilibrium is labeled $f_{\text{oae}}$.

Supernormal profits are profit levels that are greater than the average profit levels in other businesses. When individuals in a business are making supernormal profits, economic theory predicts that individuals in other businesses will be enticed into joining the more profitable activity. In this model boats join the fishery if $f < f_{\text{oae}}$ and they leave if $f > f_{\text{oae}}$.

The term "open access" refers to the fact that in this model there are no barriers to boats joining or leaving the fishery. Anyone can buy a boat, license, and gear and then go fishing.

**Maximum Economic Yield**

If fishing effort is such that the total profit flow (revenues minus costs, $$/yr) are a maximum, then the fishery is said to be harvesting the Maximum Economic Yield or MEY.

The procedure for finding the conditions that generate MEY is identical to what we did previously to find the maximum equilibrium catch (MSY) in the spawner-recruit and surplus production models.
In the diagram of costs and revenues versus fishing effort (right), we find the point on the total revenue curve where the slope is the same as the slope of the total costs line (at $f_{MEY}$).

Alternatively, we can use the marginal revenue and cost lines. Profits are a maximum at the level of effort for which marginal revenue is equal to marginal costs. At this effort level the total revenue and cost curves have the same slope.

If average revenue equals average cost (at $f_{oae}$, then the total revenue and total cost curves intersect and the fishery is at OAE.

Economists often use marginal revenues and costs, and average revenues and costs, in their analyses of economic systems.

Economists have long argued that MEY is a more appropriate objective for fishery management than MSY. It is a better objective not because it results in the greatest profits to the fishers, but because it represents the best use of productive resources.

When the marginal cost of producing fishing effort is greater than the marginal revenue of the goods produced by that additional effort, then there is a net loss to society. When effort levels are beyond $f_{MEY}$, then productive inputs (fuel, labor, capital, etc.) are being diverted away from the production of other goods or services that society values more highly.

Now let's derive some formulas for the open access equilibrium and for the maximum economic yield.

At the open access equilibrium we have $AR = AC$, equivalent to $TR = TC$.

\[ p \cdot K \cdot q \left( 1 - \frac{q}{r} \cdot f \right) = c \quad \Rightarrow \quad f_{oae} = \frac{r}{q} \left( 1 - \frac{c}{p \cdot K \cdot q} \right) \]
In terms of stock biomass this is equivalent to
\[
\begin{align*}
    r \cdot B \left(1 - \frac{B}{K}\right) &= q \cdot f_{oae} \cdot B \\
    \left(1 - \frac{B}{K}\right) &= \frac{q}{r} \left[1 - \frac{c}{p \cdot K \cdot q}\right] \\
\end{align*}
\]
Divide by B and substitute for \( f_{oae} \).

Note that \( p \cdot q \cdot B \) is the revenue flow to one unit of fishing gear and \( c \) is the cost flow for operating one unit of gear. This last equation for \( B_{oae} \) is simply a restatement of the conditions necessary for economic equilibrium, namely that revenue flows must equal cost flows at equilibrium.

At the point associated with maximum economic yield we have MR=MC.
\[
p \cdot K \cdot q \left(1 - \frac{2 \cdot q \cdot f}{r}\right) = c
\]
\[
1 - 2 \cdot \frac{q}{r} \cdot f = \frac{c}{p \cdot K \cdot q} \quad \Rightarrow \quad f_{MEY} = \frac{1}{2} \cdot \frac{r}{q} \left(1 - \frac{c}{p \cdot K \cdot q}\right) = \frac{1}{2} \cdot f_{oae}
\]
And in terms of biomass we have
\[
\begin{align*}
    r \cdot B \left(1 - \frac{B}{K}\right) &= q \cdot f_{MEY} \cdot B \\
    \left(1 - \frac{B}{K}\right) &= \frac{q}{r} \left[1 - \frac{c}{p \cdot K \cdot q}\right]
\end{align*}
\]
\[
B_{MEY} = \frac{1}{2} \left(\frac{c}{p \cdot q} + K\right) = \frac{1}{2} \left(B_{oae} + K\right)
\]
The biomass that produces MEY is halfway between the open access equilibrium level \( B_{oae} \) and the unexploited level \( K \). If fishing could be done without incurring any costs, then \( B_{oae} \) would be zero and \( B_{MEY} \) would be equal to \( B_{MSY} \). If fishing costs are greater than zero, then \( B_{oae} \) is between zero and \( K \) and the \( B_{MEY} \) is greater than the \( B_{MSY} \).
\[
c > 0 \quad \Rightarrow \quad 0 < B_{oae} < K \quad \text{and} \quad B_{MSY} < B_{MEY}
\]
The slope of the diagonal total cost line is \( c \).

When \( c \) is large, then \( B_{oae} \) will be closer to \( K \).

When \( c \) is small, \( B_{oae} \) will be closer to zero.

If fishing costs are sufficiently high relative to the price for fish, then the stock will not be exploited. We only concern ourselves with "managing" the high-priced resources.

\[
f_{oae} = \frac{r}{q} \left(1 - \frac{c}{p \cdot K \cdot q}\right)
\]

\( f_{oae} > 0 \) only if \( \frac{c}{p \cdot K \cdot q} < 1 \)

\[ \Rightarrow c < p \cdot K \cdot q \]

The quantity \( K \cdot q \) is the "virgin" CPUE. Harvesting of a stock will only begin if the harvesting costs are less than the value of the initial harvests.

In economics a rent is a return that accrues to a resource owner by virtue of the scarcity of the resource. The surplus profits that result when fishing effort is at the MEY level are often described as the economic rent or quasi-rent.

**Overfishing**

The problem of overfishing is fundamentally an economic problem. Often we have too many fishers competing for too few fish.
Fishing at the open access equilibrium (OAE) level rather than at the maximum economic yield (MEY) level results directly from the lack of property rights to the fish. The fishers do not individually own the fish and as a consequence they cannot derive the full benefits that would result from restraining their own fishing activities. "Because I don't own these fish, if I don't catch them now, someone else will tomorrow." Open access fisheries are an example of the so-called common property resource problem.

How can we move a fishery away from open access equilibrium? In the U.S. the primary management tool for regulating commercial fisheries is the catch quota, but closed seasons, fish size limits, and fishing gear restrictions are also used.

Suppose the maximum annual catch from some fish stock is restricted by a catch quota to be no greater than the maximum sustainable yield. (You need not worry about creating an unstable system because of having a quota that is permanently fixed. Instead, assume that the stock is reassessed each year and the quota is set so that it is never greater than the current rate of natural productivity.) If the OAE biomass level is less than the MSY biomass level, then to shift the system to the MSY level will require a short-term reduction in the annual catches. Under the restrictive quotas some fishers will no longer be able to cover the fixed costs associated with boat ownership and those fishers will be forced to leave the fishery. The fishers that remain will try to catch as much as of the quota as possible, and will do so as fast as possible to make certain their fishing doesn't get cut short by the quota. The result of this "race for fish" will be a shortened fishing season and higher fishing costs.

When the fishery finally gets to the new equilibrium level the stock will be larger and will support larger annual catches, but the total costs will once again be equal to the total revenue. Otherwise, the excess profits generated by the fishery would entice new boats to join the fleet.

From an economic point of view, any exploited fish stock will be overfished if there is open access to fishing. Consider the following three open access fisheries.

High costs (or low price).

Low costs (or high price).
Most fishery biologists would consider only the fishery on the right to be overfished. To a fishery economist they are all overfished.

Other Techniques for Regulating Fisheries

In addition to catch quotas, various other schemes have been used (or proposed) for controlling overfishing.

**Limited Entry.** Put a limit on the number of participants to the fishery. Usually this is accomplished by issuing a limited number of fishing permits. A permit is required to fish legally. One problem with this type of system is that we need to limit the effectiveness of the fishers in addition to the number of fishers. If the fishers are making good profits from fishing, they will be able to invest in better fishing equipment and catch fish even more rapidly.

**Tax on Landings.** Reduce the price received by the fishers by imposing a tax on the fish they catch. One problem with a tax system is that it would have to vary with changes in fish prices and fishing costs if we want to maintain the fish stock and fishing fleet as some constant target level.

**Individual Transferable Quotas (ITQs).** Fix an overall quota for the annual catch and apportion shares of the quota by auction or by assigning shares to individuals; allow share-holders to sell their shares. Having shares and guaranteed harvest rights eliminates the race to beat others for the quota; transferability of the shares allows the more cost-efficient fishers to buy shares from the less efficient fishers. Potential problems with ITQ systems include discarding of low quality fish (to stay within the quota shares) and the possibility of monopoly ownership of all the shares.