1 Efficient Management of Fishery

On Thursday we went over the open access solution to the fishery problem. Today we want to examine the economically efficient management of a fishery. To do this, let’s remove the open access problem by imagining a privately owned fishing resource. Recall that dynamic efficiency involves maximizing the present value of net benefits. Let’s go over two general models with different net benefits functions.

2 Constant Marginal Extraction Costs

In this model the cost of catching fish does not vary with the stock of fish OR with the number of fish caught. Marginal costs of harvesting are constant and represented by the symbol, $c$. Profits in each period are then given by:

$$\pi_t = (p_t - c)q_t$$

where

- $p_t =$ price of fish in period $t$
- $q_t =$ number of fish harvested in period $t$, and
- $c =$ marginal cost of harvesting a fish.

The state equation describes how the stock of fish changes over time:

$$\dot{S} = F(S) - q_t$$

where

$F(S_t)$ describes how the stock of fish changes due to natural biological reproduction (we will still use the logistic growth model for $F(S)$)

The optimization problem can be written as:

$$\max_{q_t} \int_{t=0}^{\infty} (p_t - c)q_t e^{-rt} dt$$

s.t.

- $\dot{S} = F(S) - q_t$
- $S_0 = S$

The Hamiltonian is then:

$$H = (p_t - c)q_t + \lambda_t (F(S) - q_t)$$

The FOCs are:
\[
\begin{align*}
\frac{\partial H}{\partial q_t} &= 0 = p_t - c - \lambda_t \\
\frac{\partial H}{\partial S_t} &= -\lambda_t + r \lambda_t = \lambda_t \frac{dF}{dS_t} \\
\lim_{t \to \infty} \lambda_t &= 0
\end{align*}
\]

Re-writing (1) yields:
\[p_t - c = \lambda_t\]

Notice that like with the oil problem, there is no information about \( q_t \) in this equation. We cannot solve for the optimal harvest rate in each period based on this equation alone. We’ll come back to this. Notice however that like in the oil problem, price and marginal cost are not equal. The difference between price and marginal cost is the **shadow price** or the **marginal user cost** or the **scarcity rent**. The price of fish reflects not just the cost of harvesting \( c \) but also the opportunity cost of removing the fish today. By removing a fish today I have fewer fish available to reproduce fish for the future.

Re-writing (2) yields:
\[
\frac{\lambda_t}{\lambda_t} = r - \frac{dF}{dS_t}
\]

Here is a big difference between the renewable resource problem (fish) and the non-renewable resource problem (oil). In the oil problem, the marginal user cost was growing over time at the rate of interest. Now the marginal user cost could be growing or shrinking in different periods. Recall that the logistic growth function \( F(S) \) looks like:

So the slope of this function, \( \frac{dF}{dS_t} \), is positive over some range and negative over some other range. When the stock is really high, \( \frac{dF}{dS_t} < 0 \) so the scarcity rent is changing at some rate less than the interest rate. When the stock is really high, \( \frac{dF}{dS_t} > 0 \), so the scarcity rent is changing at some rate greater than the interest rate.

The steady state solution to this problem is one in which the stock is not changing over time. That is \( \dot{S} = 0 \). It is also the case that in the steady state the scarcity rent is not changing over time. That is \( \dot{\lambda} = 0 \). Using these two features of the steady state yields:
\[
\frac{\lambda_t}{\lambda_t} = r - \frac{dF}{dS_t}
\]

and
\[
\dot{S} = F(S) - q_t \\
F(S) = q_t
\]
The steady state solution is presented graphically below.

Things to notice

- Economically efficient stock level is to the left of (smaller than) MSY. This will be true as long as the interest rate is positive.

- This graph looks a lot like the static efficiency graph from Tuesday, but somehow the net benefits are now denoted in fish and the cost is denoted as the interest rate. What's going on.

To understand the steady state solution to the problem consider the following thought experiment. I have some dollar amount, say \((p_t - c)\) to invest. I can either invest it in my fishery (think about adding a dollars worth of fish to my fish pond) or invest it in the bank. If I invest it in the bank, my marginal return on the investment will be \(r\). What if I invest it in the fish? What is the marginal product of my investment in fish? It’s \(\frac{dF}{dX}\). So if the interest rate is greater than the growth rate of the fish stock, I want to harvest all my fish and put the money in the bank. If the growth rate of the fish stock is greater than the interest rate I want to harvest no fish (or even put more fish in if I can). In equilibrium the return on these two investments must be the same.

Further, if the system is out of the steady state equilibrium, the optimum strategy is to get back to the steady state as quickly as possible. If \(r > \frac{dF}{dS}\) want to fish as many fish as possible until the rates of return are equalized. If \(r < \frac{dF}{dS}\) then want to fish as few as possible until the rates of return are equalized. The solution to this problem is often referred to as a "bang-bang" solution because of these extreme response to out of equilibrium situations.
2.1 Stock Dependent Marginal Extraction Costs

Let’s revise the model to reflect the fact that if we have fewer fish, it is more costly to harvest them. To do this the cost function now becomes $C(S_t, q_t)$. Let’s solve the new problem.

$$\max_{q_t} \int_{t=0}^{\infty} p_t q_t - C(S_t, q_t) e^{-rt} \, dt$$

s.t.  

$$\begin{align*}
\dot{S} &= F(S) - q_t \\
S_0 &= S
\end{align*}$$

$$H = p_t q_t - C(S_t, q_t) + \lambda_t (F(S) - q_t)$$

The FOCs are:

1. $$\frac{\partial H}{\partial q_t} = 0 = p_t - \frac{\partial C}{\partial q_t} - \lambda_t$$
2. $$\frac{\partial H}{\partial S_t} = -\lambda + r\lambda_t = -\frac{\partial C}{\partial S_t} + \lambda_t \frac{dF}{dS_t}$$
3. $$\lim_{t \to \infty} \lambda_t = 0$$

Re-writing (1) yields:

$$p_t - \frac{\partial C}{\partial q_t} = \lambda_t$$
Again, price and marginal cost differ by the marginal user cost. Re-writing (2) yields:

\[
\begin{align*}
\dot{\lambda} &= r - \frac{dF}{dS_t} + \frac{\partial C}{\partial S_t} \lambda_t \\
\dot{\lambda} &= r - \frac{dF}{dS_t} + \frac{\partial C}{\partial S_t} \frac{\lambda_t}{p_t - \frac{\partial C}{\partial q_t}}
\end{align*}
\]

The steady state solution to this problem is one in which the stock is not changing over time. That is \( S^* = 0 \). It is also the case that in the steady state the scarcity rent is not changing over time. That is \( \lambda = 0 \). Using these two features of the steady state yields:

\[
\begin{align*}
\dot{\lambda} &= r - \frac{dF}{dS_t} \\
r &= \frac{dF}{dS_t} - \frac{\partial C}{\partial S_t} \frac{\lambda_t}{p_t - \frac{\partial C}{\partial q_t}}
\end{align*}
\]

and

\[
\begin{align*}
\dot{S} &= F(S) - q_t \\
F(S) &= q_t
\end{align*}
\]

Will the steady state stock be larger or smaller than when costs were not a function of the stock? Intuition suggests the stock should be larger because the opportunity cost of harvesting fish is now larger. Not only will fewer fish produce fewer fish, but fewer fish results in higher harvesting costs. Let’s think about the equation:

\[
r = \frac{dF}{dS_t} - \frac{\partial C}{\partial S_t} \frac{\lambda_t}{p_t - \frac{\partial C}{\partial q_t}}
\]

and see if this is correct. If \( \frac{\partial C}{\partial S_t} = 0 \) then we are back in the world with no stock effect and the interest rate equals the marginal product of the fishery. So in order to know what happens with a stock effect, we need to know the sign of this last term.

\[
\begin{align*}
\frac{\partial C}{\partial S_t} < 0 \\
p_t - \frac{\partial C}{\partial q_t} > 0 \\
\frac{\partial C}{\partial S_t} - \frac{\partial C}{\partial q_t} < 0
\end{align*}
\]
The last term is negative. So we can rewrite as:

\[
\frac{dF}{dS_t} = r + \text{something negative}
\]

\[
\frac{dF}{dS_t} = \text{something less than r}
\]

Because of the concave (down) nature of the logistic growth function, the solution to this problem implies that we will get a higher stock rate. This is shown graphically below.

Indeed if the stock effect is very large (cost go up a lot when the stock of fish goes down) we can end up getting a steady state at a point where the slope of the logistic growth function is negative. That is something to the right of MSY.

It is for this reason that economists think that in practice, MSY might not be a bad estimate of the economically efficient stock level. Can you see why?

### 3 Fisheries management policies

There are variety of management policies in place to overcome the open access problem. They range from restricting access (seasonal restrictions, gear restrictions etc.) to price instruments (tax on fish caught), to tradable permits.
systems. Sonya will talk more about policy on Tuesday, so I will focus on just one instrument—the individual transferable quota (ITQ).

In theory an ITQ operates just like a tradable permit system for pollution. The government issues a certain number of permits to catch fish—this is called the total allowable catch (TAC). The previous analysis suggested that the MSY is generally a decent guide to the economically efficient number of permits to issue. The TAC permits are usually (but not always) issued in perpetuity to fishermen based on their historical catch rates. This is the equivalent of issuing lifetime pollution permits to firms based on historical pollution levels. Just because the permits are in perpetuity doesn’t mean that the TAC can’t change from year to year. Often permits are issued for a share of the TAC. So if ecological and economic conditions warrant lowering the TAC, every permit holder’s allowable catch goes down proportionally. Permits are then transferable so that they may be sold among fishermen. As will pollution permits we expect that different fishermen have different marginal efficiencies of catching fish and hence different marginal costs of catching fish. We’d expect fishermen who are less productive to sell their permits to fishermen who are more productive.

Advantages of ITQs in general include:

- Can lead to economically efficient use of the resource (decreases effort among those who are least productive)
• Reduces fishing effort and improves stocks
• Unlike a price instrument, the total harvest amount can be fixed.
• Should be politically viable as fishermen who are least productive get bought out (receive some money) for leaving the industry and permits are allocated without cost initially.

Disadvantages or problems with ITQs include:
• Bicatch issues—In process of catching your quota of one fish may exceed your quota for another. Fishermen will need to rebalance their holdings of quotas throughout the year which may be difficult.
• Highgrading—only want to use your quota to cover high value (big) fish. Throw smaller fish back, but they don’t all survive.
• Not appropriate when number of fishermen is extremely large because of enforcement issues.
• Politically they don’t seem to be all that popular. Economists (including me) scratch their heads about this. Why would fishermen prefer traditional management practices that have proven costly, risky, and ineffective? Any insights from the coastal folks?

We’ll spend the remaining time looking at New Zealand’s ITQ system. In the interest of full disclosure, not all ITQs have worked this well. For an interesting discussion of successes and failures using ITQs I recommend chapter 5 in Rognvaldur Hannesson’s book "The Privatization of the Oceans."

3.1 New Zealand ITQ

Features of the NZ system include:

• In 1986, New Zealand began implementing an ITQ program for most of it’s economically valuable fisheries. See the handout with the list of fish species covered by ITQs in NZ. ITQs account for 85% of total commercial catch in NZ fisheries.

• TACs developed and quotas issued for different species in different management regions. So one species may have more than one quota market associated with it if the species covers a wide geographic area with different economic and ecological characteristics (so that multiple TACs may be needed).

• Quota’s were originally given for a specific amount of fish and were granted in perpetuity and allocated free of charge.
• Initial quotas were too high (higher than MSY) and government initially bought back some quotas. This became too expensive so in 1990, NZ switched to percent of TAC quotas. This was not a popular decision as you can imagine.

• Few restrictions on quota rights. Can be sold, leased, mortgaged. If you can imagine a contract that could be drawn to govern the quota, it is probably legal in NZ.

There is also empirical evidence of increased profitability in fishing industry. As expected this increase in profitability is greater in fisheries where the initial allowable catch level was significantly reduced.

• Ownership has consolidated. The number of owners of quotas has fallen by 38%

• Lease prices reflect the annual profit flow in competitive markets. The lease price for quotas has risen 4%.

• The sale price of a quota reflects the expected present value of profits in competitive markets and these sale prices have risen 10%.

• The lease to sale price ratio reflects the rate of return on the quota. If the market is operating efficiently it should look like the interest rate. See the attached graph to see how it tracks.