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RENEWABLE RESOURCES: THE FISHERY AND WILDLIFE

The problem

Renewable resources differ from non-renewable (exhaustible) resources in that they have the capacity to regenerate. Typical renewable resources include forests, fish, wildlife generally. Some resources, like water, can also be thought of as being renewable: an aquifer (underground water reservoir) is recharged as rain water percolates down to it; a river is recharged by surface water, and so on. Some other resources, like soil, are also technically renewable: as waste biomass decomposes it adds to the soil humus.

Obviously, one ‘solution’ to any view that we are running out of exhaustible resources is to switch to renewable resources. In energy terms this would mean switching from fossil fuels (gas, coal, oil) to sources like solar power, wave and wind energy, and to fuels based on very abundant and basically renewable resources, such as hydrogen. In terms of materials it would mean switching out of, say, aggregates (stone, sand, gravel etc) into, say, wood. However, switching to renewable resources is only part of the solution. For the evidence is that renewable resources are just as much at risk of over-exploitation as non-renewable resources. Essentially, if the rate at which the renewable resource is extracted (harvested, abstracted) exceeds the rate of renewal, the resource mist eventually become exhausted.

We will illustrate this problem, and the potential solutions, in the context of the fishery. By and large, the principles are the same when applied to forests, wildlife etc, although more advanced work tells us that we cannot always generalise from the fishery to land-based renewable resources. Unfortunately, that takes us beyond B48, but we can hint at some of the issues.

State of the world's fisheries

The world's fisheries are in serious trouble. The production of fish in the world has risen fairly continuously in the last half century. Whereas developed countries have traditionally caught more fish than developing countries, the situation changed around 1990 when the LDC catch was larger than the DC catch. This reflects increasing efforts by LDCs to control their own fisheries so that an increasing proportion of the catch previously caught in their waters by DC fleets are now caught by LDC fleets. However, some DCs adopt LDC 'flags' and this confuses the situation. The gap between world production and total catch is made up of other forms of fishing. ‘Artificial' breeding - aquaculture - has grown from just 11% of the global supply in 1987 to 27% in 1996. The alleged benefit of aquaculture is that it is an assured supply without the risks of marine fishing. Environmentally, it could be argued that it reduces the pressure on marine fish where there are serious problems of stock depletion. In practice, aquaculture has its own problems, ranging from interbreeeding between escapees and wild fish, disease and pollution. Few aquacuture fisheries survive without a major disease outbreak.

Even though marine catch remains the largest source of supply, quite a few major fisheries are in decline due to over-fishing. The NorthWest Atlantic has suffered major declines, with the maximum harvest occurring in 1967. The rest of the Atlantic fisheries reached maximum yield in the period 1971-74 (World Resources 1998-9). The Atlantic code has all but disappeared. estimates that over 60% of the world's fisheries are in urgent need of management and rehabilitation.

Biological growth rates

Figure 1 shows a stylised biological growth curve for a fishery. The vertical axis has the stock of the fishery, i.e. the total (weight of) biomass. Three benchmarks are shown. At Xmax the biomass is at its maximum, no more will be added. The usual reason for this is that the resource has reached its carrying capacity: there simply isn't enough food for a larger population of fish to live on. We could also think of space as something that limits carrying capacity. At Xmin, there is a real risk that the population will collapse. Xmin could in the limit be two fish! But for many species, there is a minimum size set by social behaviour, so we could have thousands of a given species but this may not be sufficient for the population to survive. The Giant Panda is roughly in this category with just a few thousand left. Finally, we have X_0 at which the population is zero.

On the horizontal axis we show time. Look at the upper curve. It is a logistic function: it tells us that the population grows rapidly at first (e.g. because of abundant food supplies), but the rate of growth then slows down and eventually converges on Xmax. Such functions are typical of the biological behaviour of many species, but the logistic function is not the only function that could describe a renewable resource.

The lower short curve shows what happens if any perturbation pushes the population below Xmin. Basically, the population is no longer viable and goes to extinction at X_0. We will ignore this possibility in the next bits of analysis but do not forget that the possibility is there. It is known as critical depensation.

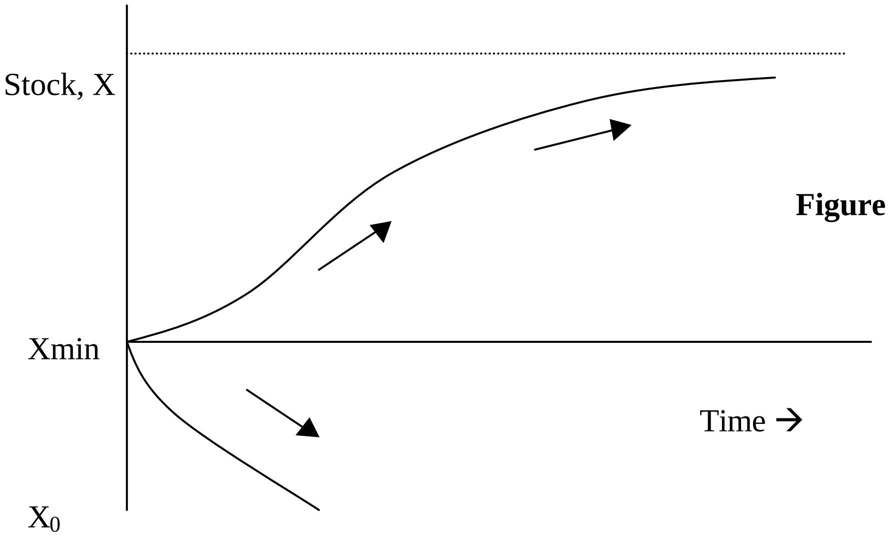


Figure 1

We now need to convert Figure 1 into a biological growth curve expressed in terms of rates of change. In other words, we want the slope of the logistic function. However, rather than looking at rates of change over time, we can relate the rate of change in the biomass (stock) to the stock itself. What is happening is that we look at the upper curve and compare the rate of change in the stock to the size of the stock as we move up the vertical axis. This produces Figure 2. Note the axes: stock on the horizontal axis and rate of growth of the stock on the vertical axis. This rate of growth can also be thought of as the sustainable yield, i.e. the harvest that could be taken without depleting the stock of the fish. But note that there are many sustainable yields – any point on the curve is a point of sustainable yield. It is a common mistake in exams and essays for people to think that the only sustainable yield is the MSY. This is not so. So be careful how you interpret the diagram.

Initially it would appear that the best yield to go for would be the maximum sustainable yield shown as MSY. We will see shortly why this is unlikely to be the case.

Figure 3 repeats Figure 2 but this time we have changed the horizontal axis again, to effort. Effort would be measured by something like the number of trawlers weighted by their engine capacity, or number of boats, or number of fishermen. It is important to see what happens when we convert Figure 2 to Figure 3. The more effort, E, there is, the lower the stock. If there was no effort, the stock would be maximised at Xmax. If there is a massive effort and all the fish are caught, the stock would go to X_0. So, whereas Figure 2 shows Xmax to the right of the horizontal axis, Figure 3 shows that Xmax will be to the left of the effort axis. (If you want to trace out precisely how to go from Figure 2 to 3, consult Pearce and Turner).

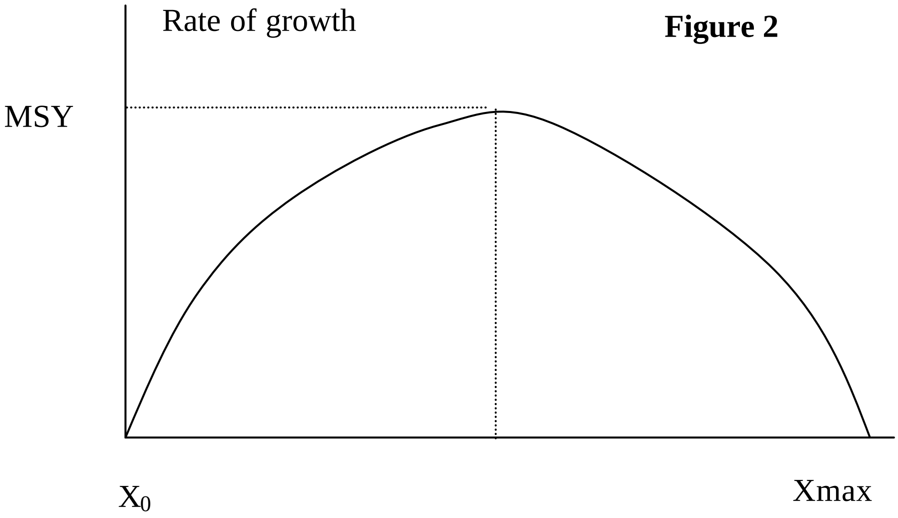


Figure 2

So far there is little economic content to the analysis. To secure this look at Figure 3 again. ‘Effort’ is clearly an input and if we multiply effort by the price of effort, we get cost. The simplest assumption to make is that the total cost of effort is a linear function as shown in Figure 4. In the same we, the curved function in Figure 3 is a yield or output curve. If we multiply output by the price of the fish sold to the market we will have total revenue. Figure 4 should in fact look very familiar. It is nothing more than the standard total cost/total revenue diagram in introductory microeconomics!

Figure 4 shows why the MSY point is unlikely to be the economically desirable sustainable yield. That is shown by the point of maximum profits, Eprof, given by the point of equal slopes of the tangent to the yield curve and the slope of the TC curve. Note that if there is sole ownership of the fishery, Eprof should come about by natural market forces. Unfortunately, most fishing regimes are not characterised this way. They often have poorly defined property rights – for example, country A may have ownership of its coastal waters but may not be able to enforce its property rights. There will be de facto ‘open access’. For many fisheries there are no property rights at all, de jure open access. Nonetheless, if there could be a single owner, or if the state can enforce property rights and collective contro, or even if the fishermen themselves can get together and manage the resource as a cooperative, then Eprof or something near it could come about.

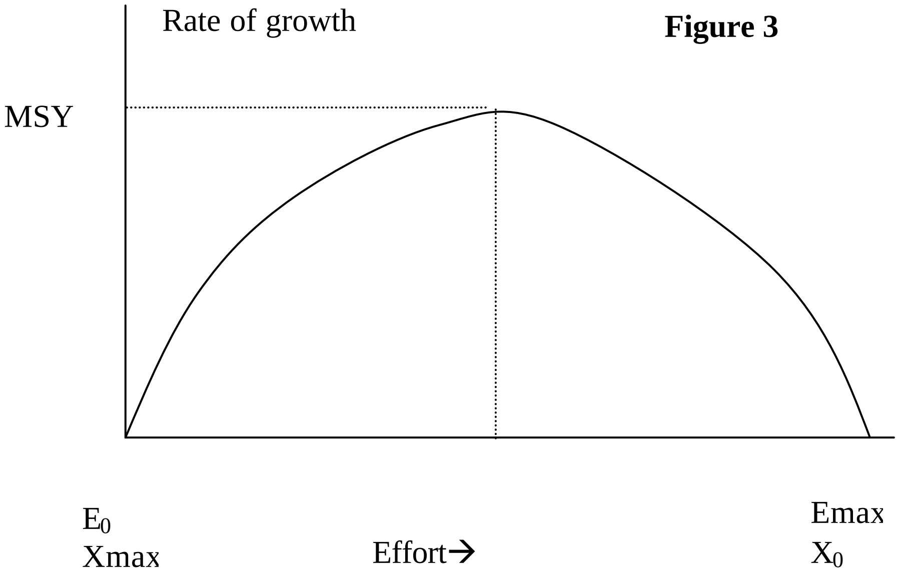


Figure 3

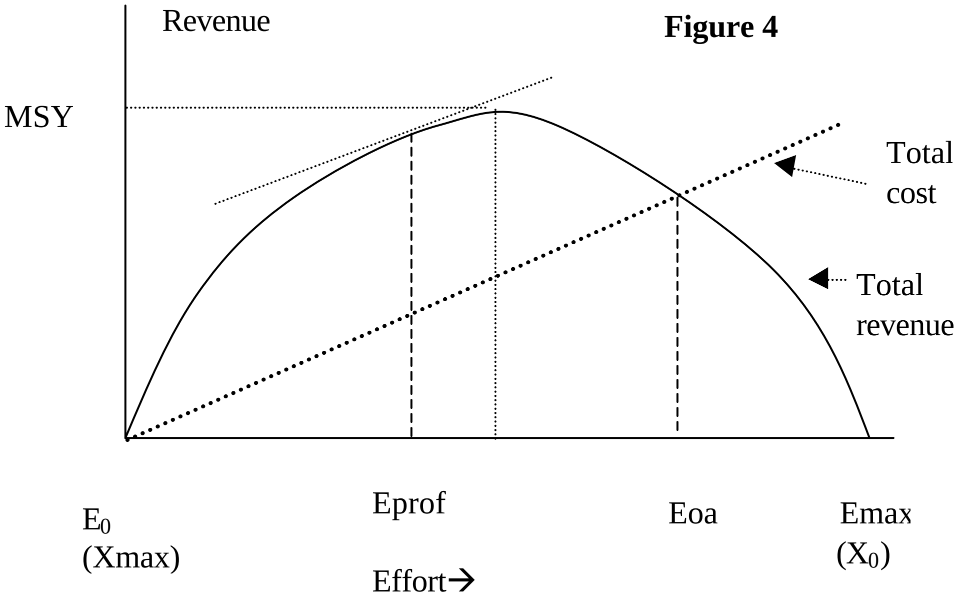


Figure 4

Another point of interest, then, is what happens when a cooperative can't be formed or there is no single owner. Then, open access is likely to occur. To find the open access equilibrium, think how each fisherman will behave. As long as there are profits to be obtained, each fishermen will make more and more effort. Or it may be that new entrants will come into the fishery. No-one has an incentive to stop at Eprof. In fact they will continue fishing until Eoa in Figure 4. Beyond this point there will be losses, so no-one will have any incentive to fish beyond Eoa. Hence Eoa is the open access equilibrium. In game theory terms, Eoa is a prisoner's dilemma solution. Cooperation to get to Eprof would be better, but each fishermen has an incentive to make themselves better off so long as everyone else has the same incentive. Cooperation pays but no-one has an incentive to take unilateral action to curtail their effort.

Note that Eoa will get further and further to the right and hence closer and closer to X_0 if TC falls. But this is exactly what has happened not just in fisheries but in wildlife contexts as well. Modern trawlers use sonar devices to track the fish. They use massive nets to cath the fish and can stay out on the ocean for longer if they have refrigeration equipment. These are the modern 'industrial trawlers'. So, the technology is bringing TC down and pushing fisheries closer and closer to those points of Xmin and critical depensation. Just the same happens with wildlife. In the 'old days' elephants were hunted with spears and conventional rifles. Today, they are hunted with high velocity rifles and can even be aerially tracked. $ wheel drive veihicles are available to make a quick getaway. Included in the TC curve is the cost of any fine or punishment (including death) the poacher may face. But if the probability of being aught is low, the 'expected value' of this cost item can be negligible. This is the standard economic theory of extinction. Its says that if costs are low, extinction is more likely. (Actually it says if the ratio of price to cost is high, extinction is more likely, but it is the same logic). Note also that if the species being hunted is slow growing (elephants, whales) there will be an even stronger likelihood of extinction. To understand this properly you need to look at the maths section eblow. But the intuition is the same as the Hotelling rule. If we leave the blue whale in the ocean to grow again, it will take many years for it to become a mature whale that we can catch. Its biological growth rate is analogous to the rate of capital appreciation in the Hotelling rule, i.e. we will get more money for the whale products the larger the whale is (assume price stays constant). So the growth rate of the whale is akin to capital appreciation. But if this rate of capital appreciation is less than the interest we can get from catching the whale now and investing the money, it will pay to catch now and invest the money rather than conserve the whale. Mercifully, most whales are now protected, but they exist in trivially small numbers compared to the early part of the 20th century.

Fisheries: a mathematical treatment

[Note, if you do not feel comfortable with the maths, be sure you understand the diagrammatic approach and forget the maths!]

X = stock of fish = the biomass
H = harvest
t = time
E = catch effort
R = total revenue
C = total cost
p = price of landed fish
c = unit cost

F(X) = growth function
H(t) = harvest as a function of time
F(X) - H(t) = rate of change of fish stock = dX/dt

Assume a simple production function of the form H = E.G(X) where G(X) is some function of X. Then E = H/G(X).

Profit ? is given by

? = R - C = p.H - c.E

Or

? = p.H - c.H/G(X)

We simplify further by conflating c/G(X) to be c(X). Then

? = p.H - c(X).H = [p-c(X)].H

The fishery is assumed to have a single owner so profits are maximised when

$PV(\prod) = \int_0^\infty [p - c(X)].H(t).e^{-st}.dt$ is maximised.

PV(?) is the present value of profits, and s is the discount rate.

We know that F(X) - H(t) = rate of change of fish stock = dX/dt, so H(t) = F(X) - dX/dt. Writing dX/dt as $\dot{X}$, and substituting H9t) in the present value equation gives:

$$PV(\prod) = \int_0^\infty [p - c(X)].[F(X) - \dot{X}].e^{-st}.dt$$

The solution (not given here) is:

$$\frac{dF}{dX} - \frac{\frac{dc}{dX}.F(X)}{p - c(X)} = s$$

which can also be written:

$$F'(X) - \frac{c'(X).F(X)}{p - c(X)} = s$$

As it stands, this is still not very revealing. First rearrange it as:

$$F'(X).[p-c(X)]-c'(X).F(X)=s.[p-c(X)]$$

Differentiating the expression [p-c(X)].F(X) produces the LHS of the above equation. Hence we can write it all as:

$$\frac{d[p-c(X)].F(X)}{dX}=s.[p-c(X)]$$

We can replace F(X) with H(t) so long as the resource is managed sustainably. [p-c(X)].H(t) can be thought of as the sustainable 'rent' from the fishery, call it M. Then the above becomes

$$\frac{dM}{s.dX}=[p-c(X)]$$

dM/dX is a sustainable rent and dM/[s.dX] is the present value of that rent. This looks more tractable. The intuition is that if we catch one more unit of fish now, we will gain p-c(X) in profits. But the catch removes from the population fish that would otherwise breed. So the current catch not only has a cost c(X) but a foregone rental equal to the present value of all the future fish that are now forgone by taking the catch now. The present value of the forgone fish is the left hand side.

<u>So, the fundamental rule for efficiently managing a profit-maximising fishery is that the marginal gain from an increase in the current harvest must equal the present value of forgone rentals arising from that harvest.</u>

Note that we have assumed throughout that p is constant. For the case where p varies with the we need to change the basic equation to

$$F'(X)-c'(X).F(X)=s-\frac{dp/dt}{p-c(X)}$$

To see the meaning of this assume c(X) = 0, i.e. harvesting is costless. Then we have:

$$F'(X)=s-\frac{\dot{p}}{p}$$

or

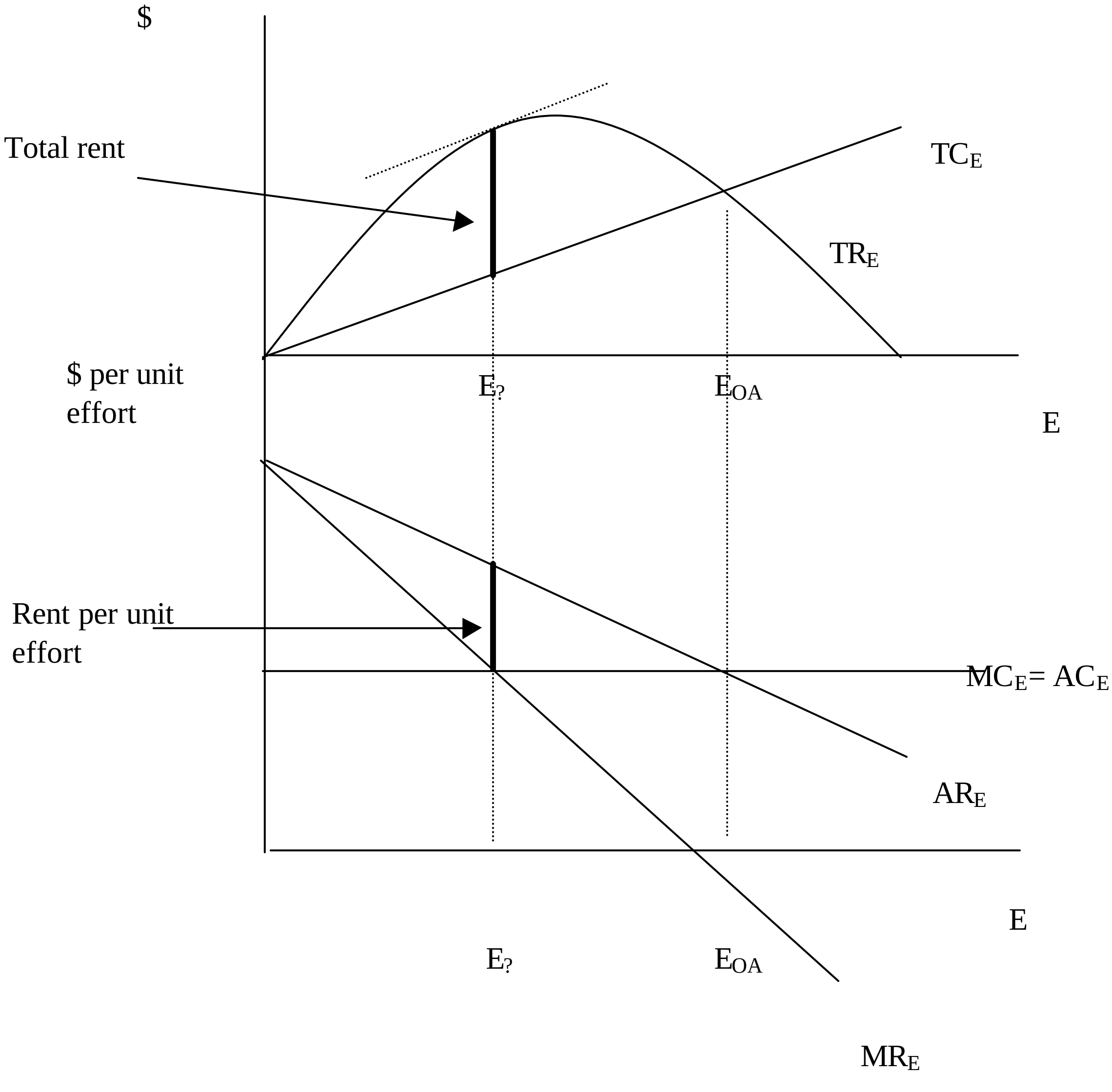
$$F'(X)+\frac{\dot{p}}{p}=s$$

which says that the 'own' growth rate (or marginal product) of the resource plus any capital gain on the marginal fish must equal the discount rate. The capital gain arises because we have implicitly assumed that prices rise over time so by not catching fish now, the fishermen can reap a higher price in the future. So, the left hand side says that if we leave the fish in the sea we will get (a) bigger fish (the 'own' growth rate) and (b) a capital gain. As long as this total asset value of the marginal fish is greater than the discount rate it pays to leave the fish uncaught. Leaving the fish alone can be thought of as an investment because the value of the fish rises through time.

Note that if s is very high, rents will be very low and the resource may risk extinction. Extinction will also occur is the ratio of p/c is high, i.e. if p is very high and/or costs are very low. If p is very high and is not expected to increase much over time then it pays to extract now. If c is very low the same effect occurs.

Regulating the fishery

Open access fisheries invariably result in over-fishing and risk extinction of the stock. In contrast, privately owned fisheries based on profit maximisation will involve less input of fishing effort and hence a higher fish stock. Consider the central diagram below.



In the diagram, H = harvest, E =fishing effort, P = product or output, R = revenue, M = marginal, A = average. Be careful if you look at textbooks. The notions of marginal cost etc. vary in meaning. Thus MC_E is the extra cost arising from one unit of effort. This needs to be distinguished from MC_H which is the extra cost arising from one more unit of harvest. In the diagram above the horizontal axis measures effort.

The profit maximising solution is given where MC_E=MR_E and the optimal effort is $E_?$. The open access solution is given by MC_E=AR_E. Open access arises because the existence of any level of profit (rent) attracts new entrants and hence the number of vessels increases until TR_E=TC_E and all rents are dissipated.

Stock externality

We note first that the OA solution equates AR_E and MC (in our diagram MC is constant and so also happens to equal MC_E). But there is an additional difference between OA and the profit maximising solution. We can write

$H = AP_E.E$

Which simply says harvest = average product of effort times the level of effort. If this is differentiated w.r.t E it gives

$$\frac{dH}{dE} = AP_E + E\frac{dAP_E}{dE}$$

The LHS is the marginal product of effort. The first term on the right hand side is the average product of effort. The remaining term is known as the stock externality or stock effect. It is negative (so don't be misled by the + sign, it is simply 'plus a negative quantity') and it measures the effect of additional effort (dE) on harvest per unit effort. Intuitively, as effort increases so the stock decreases, and hence there will be less fish catch per unit effort. Under open access each trawler ignores this effect because, for each of them, the effect is small. But across all the trawlers the effect could be large. So, the second feature of OA that contrasts with profit maximisation is that under OA stock externalities are ignored.

Notice that the last equation can be rearranged to give us

Stock effect = average product (effort) minus marginal product (effort) (remember the second expression in the RHS of the equation is negative)

If we multiply marginal and average product price and assume price is constant and equal to 1, then we can see that the stock effect is also equal to the difference between AR_E and MR_E.

Without proof, we can also assert that under profit maximisation:

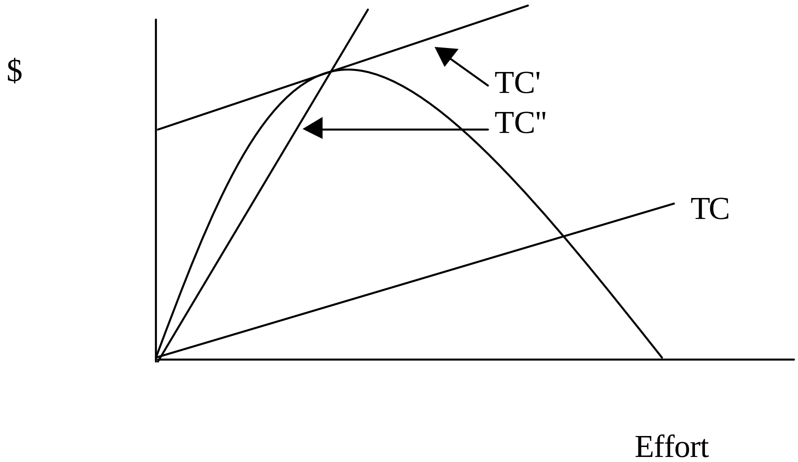
$$p = MC_H + \frac{E.dAP_E}{dE}$$

The price of fish, p, must be equated with the marginal cost of the harvest (not MC_H now, not MC_E) plus the stock effect. Under open access this will not happen. Instead, the stock effect will be ignored altogether, and, in addition, price will be equated to average cost.

Tax solutions I: a tax on effort

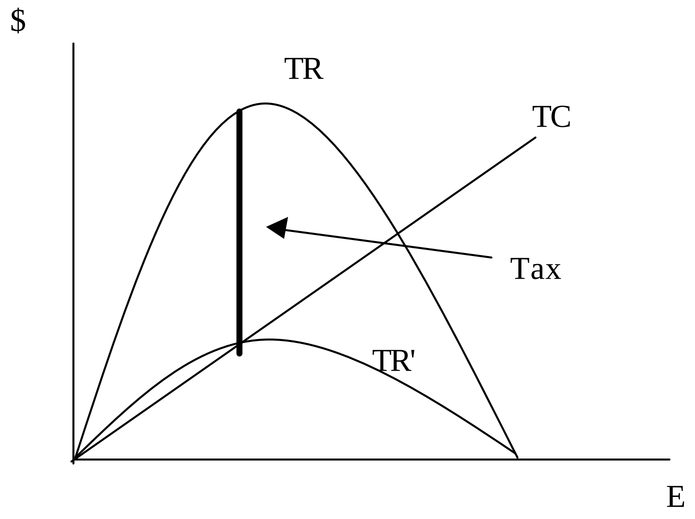
Given that open access contexts are common we want to find a regulatory solution. One solution is to tax levels of effort. The simplest way of seeing this is to work with the total curves (top of first diagram). The aim is to correct an open access situation and move to a profit maximising solution (we have ignored any other environmental externalities). We can imagine two types of effort tax. The first would simply be an annual lump sum tax that raises TC to TC' in the diagram below. The level of the tax is given by t_L. The open access fishery remains but the effect is to equate TR and TC at the optimal level of effort. Note that there is a slight contradiction in this supposition: we can hardly call the fishery open access if there is some licensing authority imposing the tax. Notice also that TC' lies above TR so why would anyone fish at all with such a tax? The answer is that the tax is on the fishing industry as a whole, so the tax born by each fisherman is a fraction of the total tax.

The second solution is to impose a tax per unit effort which has the effect of swivelling TC to become TC". Again, the optimal level of effort is achieved even though TC"=TR.



Tax solutions II: a tax on catch

The harvest itself could be taxed. The effect of a harvest tax is to shift the TR curve downwards as shown below. TC=TR produces the optimal catch. Such taxes are rare. Revenues vary as prices change so computing the tax could be very complex, and some fish may be landed outside monitoring areas. The effect on effort also means that some fishermen will go out of business.



Allowable catch quotas

A common regulatory procedure is to set a 'total allowable catch' (TAC). TACs are often set equal to the maximum sustainable yield (the turning point of the TR curve above) which we have already noted is not the same thing as an economically efficient solution. The problem with TACs is that they are set on the total catch without any reference to the way in which the total catch is distributed between trawlers. The effect is to initiate a 'race' to catch as much as possible as quickly as possible. What might have been caught over a year, say, may now be caught in a few months, with the rest of the year being idle for the fishermen. But there is also a good chance that the TAC will itself be breached as fishermen become more and more desperate to catch what is there. Even if effective, the TAC causes a shortage of supply, pushing fish prices up and inducing more new entrants. So, even if the TAC is observed, there are numerous economic inefficiencies. The most common problem, however, is that the industry spends resources challenging the scientific basis for the TAC, usually resulting in a compromise for a catch bigger than that consistent with sustainability of the stock. The end result is a gradual running down of the stock.

Tradable individual quotas

Whereas the TAC approach focuses, inefficiently, on the total catch, quotas both set a TAC and distribute shares of the quota to each vessel. Quotas are usually 'grandfathered', i.e. allocated according to past fishing effort, but they can be auctioned. In the grandfathering case there are no revenues to the license giver (the government say), but in the auctioning case there will be. In the former case the 'rents' accrue to the fishermen, in the latter case they accrue to the government. Quotas can also be tradable or non-tradable. In theory, non-tradable quotas should avoid the 'race to harvest' which was noted as a problem under TAC. Each vessel has its quota and as long as everyone else observes their quota, and as long as the TAC has been set sensibly, each vessel will be assured of its catch. In practice, the race to harvest may still apply because firms may doubt the TAC and will want to get there first, and there may be doubts about the likelihood that others will catch only their quota.

Note that individual quotas can be expressed in terms of allowable catch per vessel or firm, or in terms of allowable effort (probably measured by the total horsepower of the vessels). Unless those setting the limits are confident they can translate effort quotas into an equivalent level of catch, setting effort quotas could be risky for the sustainability of the fishery.

The tradability of quotas overcomes many of the problems. High cost fishermen will sell their quotas to low cost fishermen and leave the industry.