Classes of Natural Resources

A. Nonrenewable, or Exhaustible – e.g. coal deposit, oil deposit, body of iron ore (the subject of Ec. 471)

B. Renewable – a resource that is capable of growth, or regeneration, e.g. a forest, a fishery resource

The use of the term "Exhaustible" can be misleading -often impossible to physically exhaust category <u>A</u> natural resources. Many category <u>B</u> natural resources can in fact be physically exhausted -examples

ECONOMIC BASE of a REGION
(e.g. British Columbia)

-goods and services produced by the Region that are sold primarily beyond the Region's borders

All other productive activities in the Region are seen as being dependent on this BASE.

The Economic Base of the Region that is British Columbia is heavily oriented towards Natural Resources –forestry in particular.

Natural Resources as Capital

Capital is any asset that is capable of yielding a stream of economic returns through time – as opposed to a consumer good or service.

Real capital vs. financial capital

All natural resources, non-renewable and renewable, fall within this definition of real capital

The World Bank 2005 publication: ***Where Is the Wealth of Nations?*** – based upon the fundamental idea that society's income through time is produced by its stock of real capital, which consists of:

I. Produced capital (person made capital)

II. Natural capital

III. Intangible capital (human and social capital)

Traditional national income accounting only recognizes produced capital. The World Bank and others call for "green accounting"

Development seen by the World Bank as a process of real capital portfolio management through time (portfolio – a set of assets).

Natural Capital vs. Produced Capital (person made capital)

a. Natural capital assets come as endowments of nature

b. Can be optimal –within limits –to deplete, to disinvest in, Natural capital
   - deliberate disinvestment of Produced capital never discussed. No nation is ever seen as having more than enough Produced capital.

Our ability to manage these resources is affected by the existence, or lack of existence, of resource property rights. The property rights, if they exist, may either be private, or public (i.e. state), property rights. As a first step, we must define what we mean by property rights.

Property Rights – Text definition

“A bundle of characteristics that convey certain powers to the owner of the right”

Key characteristics

I. Exclusivity

II. Enforceability

III. Transferability

IV. Divisibility

Characteristics I and II are crucial

-the Text’s example of a farmer holding a deed to farm land.

Absence of property rights:

“common pool” resources

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Sustainable Harvesting and Resource Investment: A Crude Example

A Forest

At the end of period **t**, the volume of wood in the forest is estimated to be equal to **X** cubic metres.

If no harvesting (logging) were to occur in the forest over the following period: **t + 1,** the volume of the wood in the forest at the end of period **t + 1** would be estimated to be equal to:
X + Y cubic metres.

The additional **Y** cubic metres accounted for by the net natural growth of the forest.

Suppose now that, over **t + 1**, **Y** cubic metres was extracted from the forest due to harvesting, i.e. logging. The volume of wood in the forest at the end of **t + 1** would, other things being equal, be **X** cubic metres: (**X + Y) – Y = X**

In theory, **Y** cubic metres could be extracted from the forest, period after period, with the volume of wood in the forest remaining stable. We would talk about harvesting the forest on a **"Sustainable Basis"** - "cropping the growth", or "skimming off the growth".

If the harvest over **t + 1** should be less than **Y** cubic metres, we would have positive investment in the forest. The forest asset, measured in terms of volume of wood, would increase.

If the harvest over **t + 1** should exceed **Y** cubic metres, we would have negative investment in the forest asset – also known as disinvestment.

If the forest was harvested on a "sustainable basis" over **t + 1**, i.e. the harvest over the period equal to **Y** cubic metres, then the investment in the forest asset is equal to zero – neither positive nor negative.

-Size of the sustainable harvest will be influenced by the size of the forest (measured in cubic metres of wood).

Sustainable Yield (or harvest) – a concept that we shall see coming up over and over again.

The Theory of Capital vs . The Theory of Investment

Theory of Capital – about determining the optimal Stock of capital.

Theory of Investment –concerned with flows –

positive investment – building up a stock of capital through time.

negative investment (disinvestment) - reducing a stock of capital through time.

The Theory of Investment is designed to tell us how rapidly we should approach the optimal stock of capital. Should the ***rate*** of investment be fast or slow.

The economist's Theories of Capital and Investment lie at the heart of Natural Resource Economics, as applied to both renewable and non-renewable natural resources.

Before we can say anything about the Theories of Capital and Investment, we have to review the concepts of Present Value and Future Value

The Interrelated Concepts of Present Value and Future Value

Present Value (PV) used to express the current, or present day, value of an asset (or return) to be received at a certain future date.

Future Value (FV) relates to value of an asset, if held, at a certain date in the future.

Key link between PV and FV provided by the **interest rate** – also referred to as the **rate of discount**.

Example:

$1,000 held to day - Present Value

Suppose that the relevant annual rate of interest is 5.00% (no compounding within the year)

At the end of one year, the $1,000 will be worth:

$1,000(1+0.05) = $1,050 ,which is the Future Value (I year) of the original $1,000

Denote the relevant interest rate in decimal terms as: δ.

In general terms: Future Value (I year) is:

$$FV = PV(1+\delta)$$

and

$$PV = \frac{FV}{(1+\delta)}$$

in our example, we have $\delta = 0.05$

Suppose now that I am to receive \$100 at the end of 1 year. Then:

$$PV = \frac{\$100.00}{(1+0.05)} = \$95.24$$

Suppose that I was to receive the \$100 in two years time, what then would the PV of the \$100 be? We would have:

$$PV = \frac{\$100}{(1+0.05)^2} = \$90.70,$$ why?

To generalize, let R be the amount to be received at a future time t. Then:

$$PV = \frac{R}{(1+\delta)^t}$$

The present is: t = 0.

Now suppose that we were to receive a series of equal payments of $100.00 from t = 1 to t = 5, and continue to suppose that δ = 0.05

$$PV = \frac{\$100}{(1+0.05)^1} + \frac{\$100}{(1+0.05)^2} + \frac{\$100}{(1+0.05)^3} + \frac{\$100}{(1+0.05)^4} + \frac{\$100}{(1+0.05)^5} \approx \$432$$

R = $100 is now the amount to be received period after period.

When R is constant, period after period, we can generalize and express PV in equation form as:

$$PV = \frac{R}{\delta}\left(1 - \frac{1}{(1+\delta)^n}\right)$$

where ***n*** is the last period in which R is received. In our example, we have ***n*** = 5.

Two Extreme Cases

a) $\boldsymbol{n}=1$

b) $\boldsymbol{n}=\infty$

a) $PV = \frac{R}{(1+\delta)}$

b) $PV = \frac{R}{\delta}$

Some Investment Decision Rules

To begin, a bond that pays interest forever and ever, and is never redeemed, is called a *Perpetual* (example – Consols – Britain, late 19th Century).

The value of such a security is equal to the PV of the stream of interest payments over time.

Consider such a *Perpetual* and suppose that R = \$100, and that $\delta = 0.05$

Since, $\boldsymbol{n} = \infty$, we can say that:

$$PV = \frac{\$100}{0.05} = \$2,000$$

When would it pay me to buy the security? – clearly, it would pay me to buy the security, if the cost was less than $2,000.

If the cost is $1,500, BUY. If the cost is $2,500, IGNORE.

If the cost is $2,000, I will be on the margin of indifference.

Denote the cost of a marginal investment – addition to the stock of capital - as **C**

An investment decision rule, which provides an answer to my Theory of Capital question:

Invest up to the point that:

C = PV, where **PV**, in this case, is the present value of the stream of economic returns from this marginal addition to the stock of capital, from $t = 0$ to $t = \infty$.

In the case of the *Perpetual* bond, we have

PV = $2,000.

So invest up to the point that **C = $2,000**

In the bond market, the price of the bond (C) would, in fact, be driven up, or down, to C = $2,000

Next, the yield, rate of return, or "own rate of interest" on a marginal investment.

In all of the cases that we shall come to deal with, the period by period return from a marginal investment (positive) will be constant and go on forever, just like our *Perpetual* bond. This will greatly simplify life for us.

Denote the yield on a marginal investment as *y*

We have: $y = \frac{R}{C}$

Suppose that we have, as before:

C = $2,000; and R = $100

then:

$$y = \frac{\$100}{\$2,000} = 0.05$$

or y = 5.0%

A condition for capital asset portfolio equilibrium is that all assets of a common risk class be found to offering the same yield, or rate of return.

It is reasonable to suppose that this common rate of return is the same as our discount (interest) rate, δ

The gives us another Investment Decision Rule.

If $y > \delta$, go on investing in the capital. Invest up to the point that:

$$y = \delta$$

In our case, where R is constant and goes on forever and ever, it easy to show that the two Investment Decision Rules are identical:

$C = PV$, our first Investment Decision Rule; but

$$PV = \frac{R}{\delta}$$

hence:

$$C = \frac{R}{\delta}$$

$y = \delta$, our second Investment Decision Rule; but

$$y = \frac{R}{C}$$

thus we have:

$\frac{R}{C} = \delta$, which, upon re-ordering terms, is:

$$C = \frac{R}{\delta}$$

We shall encounter just these sorts of Investment Decision Rules in our discussion of the economics of fisheries management, and of the economics of forestry management.

The stocks of capital will be seen to consist of stocks of fish and stands of trees.

Fisheries

Some distinctions;

Marine vs. Inland Fisheries

Capture (wild) Fisheries vs. Aquaculture

Types of Fishery Resources

I. True fish:

   a. Finfish ,e.g. Pacific salmon, Pacific halibut

   b. Shellfish, e.g. shrimp, crab

II. Sea mammals, e.g. seals, whales

III. Marine plants – seaweed, e.g. kelp. Irish moss

We will confine our discussion to marine (ocean) capture fisheries – reasons for.

World marine capture fisheries have a total annual harvest of approx. 80 million tonnes, with a "first" value in excess of US$80 billion.

Employment, direct and indirect, over 120 million, world wide.

(Source: Food and Agriculture Organization of the UN [FAO])

These fisheries are overwhelmingly base on Type I resources.

<u>Difficulties in the Economic Management of Capture Fisheries</u>

1. The fish, and their interaction with the surrounding aquatic environment, are very difficult to observe.

    -species interaction:

    (a) competition for food resources

    (b) predator-prey relationships.

2. The fish are, in most instances, mobile. Some species may travel over several thousand kilometers during their life cycle – the example of Pacific salmon

The consequence has been, in the past at least, that it is/was very difficult ,or more to the point, very costly to establish effective property rights to these resources, be the property rights private or public.

Capture fishery resources historically seen as the classic example of "common pool" resources.

By the middle of the 20th century, the "common pool" nature of these resources was being seen to lead to serious problems – overexploitation and severe economic waste.

"Everybody's property is nobody's property"

Today, the environment –oceans, atmosphere –have similar problems.

BUT – up until the end of World War II, "common pool" nature of capture fishery resources did not seem to matter all that much, other than in a few isolated cases.

Thomas Huxley, one of the greatest biologist of 19th century Britain, stated in 1883 that the great ocean fishery resources of the world are “inexhaustible”. The best fisheries management, he argued, is no management at all.

This view was enshrined in international law, in the form of the doctrine of the Freedom of the (High) Seas – goes back to the 17th century.

Legal distinction between coastal state Territorial Sea and the High Seas. (coastal state –state with significant marine coast line, e.g. Canada, vs. landlocked state ,e.g. Austria)

Coastal state exercised full property rights within the Territorial Sea, but the Territorial Sea was very narrow, historically 3 miles – roughly 4.8 kilometers. Everything else constituted the High Seas.

Under the doctrine of the Freedom of the Seas, fishery resources in the High Seas are open to exploitation by all - fishery resources true “common pool”.

Justification: up until the 19th century too costly to exploit these resources extensively. The resources were protected by economics. The natural capital was “free” capital.

The economic protection of these great ocean fishery resources was undermined by advances in fisheries technology, which lowered harvesting costs – economic protection was beginning to fray, even as Huxley spoke in 1883 – e.g. shift from sail to steam. All of this took time

-the two World Wars and fish stocks in the North Sea.

First major attempts to regulate ocean fishery resources through international agreements – very limited success.

Following World War II, coastal states began extending their jurisdictions over ocean resources unilaterally. UN intervened to try and put some order into the process. Convened the First UN Conference on the Law of the Sea in 1958, and a second conference in 1960. The two conferences did little about capture fisheries management.

The Third UN Conference on the Law of the Sea was held between 1973 and 1982. This conference revolutionized the management of world capture fisheries.

The Conference brought forth the 1982 UN Convention on the Law of the Sea.

-Under the 1982 UN Convention, coastal states, such as Canada given the right to establish 200 nautical mile (370 km., approx.) Exclusive Economic Zones (EEZs). Within the EEZ the coastal state, to all intents and purposes, has property rights to the fishery resources contained therein. Whether the coastal state can make these property rights effective is a different matter.

-The EEZ regime is now almost universal. Canada has EEZs off its Atlantic and Pacific coasts – Arctic EEZ not fully settled.

-Estimated in 1982 that, if EEZ regime became universal, the EEZs would encompass 90% of the commercially exploitable capture fishery resources of the world - massive reduction in Freedom of the Seas, as applied to fisheries, or so it seemed in 1982.

The EEZ regime has mitigated the “common pool” problem of world capture fisheries, but it certainly has not eliminated it. Many coastal states find that their intra-EEZ property rights are difficult to implement. Still have overexploitation and economic waste within EEZs.

Furthermore, because of the mobility of most capture fishery resources, many of the fishery resources cross the EEZ boundary into EEZs of neighbouring coastal states, or into the remaining High Seas –the Shared Fish Stock problem, which we shall discuss at a later point.

It was assumed by many in 1982 that High Seas fishing would be at most a minor problem. This assumption has proven to be dramatically wrong. UN forced to convene another international conference to deal with the problem – biggest problem – fishery resources crossing the EEZ boundary into the High Seas – so called Straddling Stocks

Common pool characteristics of fishery resources now invariably lead to overexploitation and economic waste.

Contrast fishery resources with forestry resources. Trees are visible and stationary. Relatively easy to establish and enforce property rights – private or public.

On the other hand, the environment –narrowly defined –has common pool problems similar to fisheries.

In any event, overexploitation of world capture fishery resources continues to be a serious problem, although one that is hopefully leveling off.

FAO based figure, which is bit dated, but still gives a clear idea of the problem.

Some More Description

Classes of Finfish Species:

A. Demersal Species (groundfish, or whitefish), e.g. cod, halibut

B. Pelagic Species, e.g. herring, tuna

C. Anadromous Species ,e.g. salmon

Classes of Gear in Capture Fisheries

1. Lines and hooks

2. Traps and pots

3. Encirclement gear

4. Entanglement gear

Historically, Pacific salmon was the most important species harvested by the B.C. fishing industry. This has now changed. Demersal species (groundfish) are now the most important, followed by shellfish

Bioeconomics

Every respectable Economic Model of the fishery has a Biological Model as its foundation.

If the biological model is misspecified, the economic model built upon the biological model will, at best, be worthless

So close is the link between biology and economics in fisheries economics that we now talk in terms of ***Bioeconomics***

This Fundamental Proposition requires a brief overview of biological models of fishery –

-a still useful 49 year old source, by two famous marine biologists, R.J. Beverton and M.B. Schaefer

Schaefer and Beverton (1963), *"Fishing Dynamics- Their Analysis and Interpretation"*

The focus is on a stock of fish of a particular species (a single species model), in particular region
-stock measured in terms of weight – ***biomass**.*

-concentrate, not on the total biomass, but on:
Fishable Biomass. Later, we will talk simply about the biomass, but what we will be referring to is really the *fishable biomass*.

-through time Fishable Biomass (FB) will increase, due to:

(a) recruitment
(b) growth of individual fish in FB

-through time the FB will be depleted due to:

(i) natural mortality
(ii) fishing mortality

-a diagrammatic representation

Now let **x** denote the FB. The % rate of growth of x can be represented as follows:

(I) $(dx/dt)/x = z(x) + g(x) - M(x) - f(E) + \eta$, where z, g, M and f denote the rates of recruitment, growth of individual fish in FB, natural mortality and fishing mortality respectively. Note that z, g and M are assumed to be functions of x.

f is seen as a function of E – fishing effort, which we can interpret as a combined flow of labour, produced capital and ancillary services devoted to harvesting (often measured in standardized vessel days).

η denotes a noise term, with mean = 0

Setting η = 0, a Steady State ,i.e. (dx/dt)/x = 0, will have been achieved when:

(II) $f(E) = z(x) + g(x) – M(x)$

refer to the Right Hand Side (R.H.S.) of Eq. (II) as the "net natural rate growth of the FB" . Eq.(II) then just says that a steady state will be achieved when the rate of fishing mortality is equal to the net natural rate of growth of the stock (FB)

Now take (II) and multiply both sides by x, so that we have:

(III) $f(E)x = [z(x) + g(x) – M(x)]x$

implying that, at the steady state, the harvest – f(E)x is equal to the net natural growth of the stock – essentially skimming off the growth of the resource. But this Steady State situation means that the resource is being harvested on a “sustainable” basis.

Beverton and Schaefer tell us that, ideally, biologists would like to be able to estimate all of the parameters in (I), for given fishery resources, but that this has proven to be very difficult – no evidence that these difficulties have vanished over the intervening 49 years.

Simplifications required. Two broad approaches:

A. Beverton – Holt – attempts made to measure the parameters in context of a discrete time model, but it is usually assumed that the period by period rate of recruitment remains constant. Then focus on behaviour over time of individual sets of recruits – cohorts or year classes.

For analytical purposes, economists find that the B-H type of model is just what they want in analysing the management of aquaculture resources. The B-H model is used extensively in capture fishery management.

In developing analytical economic models of the management of capture fisheries, however, B-H models create intractable difficulties – reasons for. Having said this, it will be seen that economists do in fact make extensive use the B-H models in empirical analysis of such fisheries

In developing analytical models of capture fisheries, economists look to the second approach:

B. "General Production" models, in which key parameters are merged – what mathematicians call **"lumped parameter"** models.

Perhaps the most famous of such General Production models is the one developed by M.B .Schaefer, in the early 1950s. The Schaefer model provides the foundation for most of the economic models of the fishery that we will be examining, so let us take a close look at it.

The Schaefer Model

We have:

(1) $dx/dt = F(x, \mathbf{A})$, where x denotes the biomass, and **A** denotes the aquatic environment, assumed to be constant. Hence (1) can be re-written as:

(1a) $dx/dt = F(x)$

- it is assumed that F(x) corresponds to the "logistic" law of population growth (19^{th} century Verhulst model population growth)

(2) $dx/dt = F(x) = rx\,[1 - x/G]$,

where G, a constant, is the "carrying capacity", or natural equilibrium biomass level (biomass cannot grow forever), and where **r** is the "intrinsic growth" rate.

Let us note the following: The %, or proportional, growth rate of the biomass is – $F(x)/x = r[1 - x/G]$

$$\lim_{x\to 0} F(x)/x = r$$

thus **r** is the *maximum* % growth rate

Now introduce harvesting. We have:

(3) $dx/dt = F(x) - h(t)$

The harvest production function is given by:

(4) $h = qE^{\alpha}x^{\beta}$, where q, a constant, is the "catchability" coefficient, a constant, an index of the state of fishing technology, and where the exponents, α and β, are constants

Note that this production function looks a lot like the Cobb-Douglas production function that we are familiar from Ec. 201/301: $Q = AK^{\alpha}L^{\beta}$, where Q is the quantity of output, where A is a constant, and where $\alpha + \beta = 1$.

-a critical assumption in the Schaefer model is that the fish are uniformly spread throughout the relevant aquatic environment, regardless of density. This amounts to assuming that $\alpha = \beta = 1$ – unlike the Cobb-Douglas production function.

In any event, with $\alpha = \beta = 1$, by assumption, we rewrite (4) as:

(4a) $h = qEx$

This assumption has, as we will see, important policy implications

By the way, what is the rate of fishing mortality in the Schaefer model? It is, simply: $qE = h/x$

-a diagrammatic representation of the Schaefer model, and the concept of sustainable harvest, or yield, and Maximum Sustainable Yield (MSY).

We next have to consider the relationship between fishing effort (E) and sustainable yield (harvest). This we need for the first economic model of the fishery.

Consider the following diagrams.

The diagrams show the relationship between E and sustainable yield, or harvest for two possible rates of E, E_1 and E_2 . We could carry out the same procedure for every other possible rate of E.

Fortunately, we do not have to. From the Schaefer model, we can develop a functional relationship between E and sustainable harvest (yield), which we shall denote as: h_s.

We start off by returning to our harvest production function:

(I) $h = qEx$

We note that, if harvesting is taking place on a sustained yield basis, then it will be the case that:

(II) $h = F(x)$,

recalling that $F(x) = rx[1 – x/G]$,

we can (II) re-write as:

(IIa) $qEx = rx[1 – x/G]$

Associated with any sustainable harvest there will be an equilibrium, steady state, level of the biomass, x.

From (IIa) we can derive an equation for x, representing the equilibrium, steady state, level of x, given a particular E:

(III) $x = G[1 - (q/r)E]$

Now substitute for x in Eq. (I) [the harvest production function], from (III), and we have an equation for sustainable harvest (yield), h_s:

(III) $h_s = qE\{ G[1 - (q/r)E]\}$

$= qGE – (q^2G/r)E^2$

(IIIa) $h_s = uE – vE^2$,

where $u = qG$, $v = q^2G/r$, and where u and v are obviously constants

-a diagrammatic representation

The concept of “Biological Overfishing”. $E > E_{MSY}$,

which will cause the biomass to fall below x_{MSY}

-more diagrams

The H. Scott Gordon Economic Model of the Fishery and Resource Rent Dissipation

This model, which appeared in 1954, marks the beginning of modern fisheries economics.

It is a “static” economic model, because this was the best that Gordon could do with the tools available to him at the time.

While it has drawbacks, because of its static nature, it has important lessons, and continues to have a major influence on policy makers. Moreover it provides the foundation for the dynamic economic model of the fishery that we will examine later.

Basically what Gordon does is to take the Schaefer based fishing effort (E) sustainable yield (harvest) relationship that we have discussed and add in prices and costs to make it an economic model.

-consider the following diagram

Key Assumptions Underlying the H. Scott Gordon Model

1. Demand for harvested fish is perfectly elastic. Hence, price for harvested fish, ***p***, is a constant.

2. ***p*** provides a perfectly adequate measure of MU of harvested fish to society

3. Supply of E is also perfectly elastic. Hence, the unit (average) cost of E, ***b,*** is a constant. Moreover,
   b = $MC_{E.}$ Also note that the total cost of E is simply:
   TC_E = ***b***.E

4. There is no discrepancy between private and social cost of E.

5. The fishing industry is perfectly competitive.

6. Human and produced capital in the fishery are both “perfectly malleable”, meaning that they can be easily and costlessly moved in and out of the fishery.

The implication of assumptions 2. and 4. combined is that we are living in a First Best World.

<u>Some Further Definitions:</u>

Value of the Marginal Product of E (VMP_E)

Total Revenue with respect to E:

TR_E = (Sus. Yield).***p***

$$\frac{d(TR_E)}{dE} \equiv VMP_E$$

Value of the Average Product of E (VAP_E)

$$VAP_E = \frac{TR_E}{E}$$

Marginal Cost of E (MC_E)

TC_E = ***b***.E

$$MC_E = \frac{d(b.E)}{dE} = b$$

Average Cost of E (AC_E)

$$AC_E = \frac{b.E}{E} = b$$

Note that MC_E = AC_E

Next note it will always be the case that
VMP_E < VAP_E, except when E = 0.

TR_E = ***p***.h_s = ***p***[uE – vE^2]

Thus VMP_E = ***p***[u – 2vE] (do the differentiation)

$$VAP_E = \frac{TR_E}{E} = p[u - vE]$$

Resource Rent defined – Joan Robinson

“The essence of the conception of *rent* is the conception of a surplus earned by a particular --- factor of production over and above the minimum necessary to do its work. The conception of rent----is closely connected with the ‘free gifts of nature’—the essential characteristic of which is that they do not owe their origins to human nature”
Joan Robinson, *The Economics of Imperfect Competition*

The rent associated with the “free gifts of nature” (natural resources) we term **Resource Rent**.

The Gordon Argument

Applying elementary Welfare Economics, Gordon maintains that in a First Best World, E (basically combined labour and produced capital services) should be allocated to the fishery up to the point that:

$VMP_E = MC_E$ - reasons for

It so happens that at the point that $VMP_E = MC_E$ total Resource Rent will be maximized – economists refer to this as **MEY – Maximum Economic Yield**

Denote total Resource Rent as: RR

$RR(E) = TR_E - TC_E$

First order condition for a maximum is:

$$\frac{d(RR)}{dE} = 0$$

$$\frac{d(RR)}{dE} = \frac{d(TR_E)}{dE} - \frac{d(TC_E)}{E} = 0$$

But:

$$\frac{d(TR_E)}{dE} \equiv VMP_E$$

$$\frac{d(TC_E)}{E} \equiv MC_E$$

Hence, the first order condition implies that:

$\mathbf{VMP_E = MC_E}$

Denote the E corresponding to MEY as $\mathbf{E_{MEY}}$.

In the absence of property rights, private or public, the fishery will not be in equilibrium at $E = E_{MEY}$.

Suppose that we are at $E = E_{MEY}$. There is no landlord (sealord) to appropriate the Resource Rent. The rent does not disappear, but rather becomes incorporated into the fishing firms' economic profits.

Theory of Perfect Competition in the Long Run – the Zero Profit Theorem – the industry will expand or contract up to the point that the economic profits of the firms in the industry equal zero - a comment on economic profits.

At $E = E_{MEY,}$ the economic profits are definitely positive, hence the fishing industry is not in equilibrium.

The fishing industry will therefore expand (E will increase), and will go on expanding, until $\mathbf{TR_E = TC_E}$, $E = E_{\infty}$.

If $TR_E = TC_{E,}$ then $VAP_E = AC_E$ (why?)

But we know, given the Gordon assumptions, that

$AC_E = MC_E$

It thus follows that, at $E = E_\infty$, we have: $VAP_E = MC_E$

BUT we know that **$VMP_E < VAP_E$** (except in the uninteresting case when E = 0).

HENCE, at $E = E_\infty$,. **$VMP_E < MC_E$** . The optimal allocation rule has been violated.

We end up with an overallocation of E to the fishery.

Furthermore, at $E = E_\infty$, the Resource Rent has been completely dissipated. RR = 0.

The resource, as a "natural" capital asset, is yielding zero!

Gordon referred to $E = E_\infty$, as:

BIONOMIC EQUILIBRIUM - reasons for

What is not shown clearly in the Gordon model, as we have presented it, is the fact that there is more going on than an over allocation of labour and produced capital service (E) to the fishery. The fishery resource is being overexploited from society's point of view – this form of natural capital is subject to excessive disinvestment from society's point of view, when we are at **BIONOMIC EQUILIBRIUM**. This will become clear later on.

The World Bank/FAO publication: *The Sunken Billions: The Economic Justification for Fisheries Reform* (2009), estimates that world capture fisheries are losing potential resource rent in the order of US$50 billion per year – root cause – ongoing "common pool" characteristics of many of the world's capture fisheries.

Suppose now that the fishing industry was not perfectly competitive, but was rather under the control of a single firm – "sole owner"

What then would the profit maximizing "sole owner's" policy be? It would be to stabilize the fishery at $E=E_{MEY}$. Thus "sole ownership" leads to a socially desirable outcome - a seemingly perverse result from the "common pool" conditions of the fishery.

The Gordon economic model of the fishery provides a classic example of **Market Failure**.

The market sends out incorrect signals (from society's point of view)

This provides a case for government intervention (management)

As we shall see, most government management of the fishery is designed to counter the negative consequences of the "common pool" nature of the fishery.

<u>Gordon's Secondary Conclusion</u>

A secondary conclusion arising from the Gordon model is that the marine biologist's management criterion of MSY is incorrect.

We have: $TR_E = \boldsymbol{p} . h_s$
Maximizing h_s implies maximizing TR_E
First order condition for a TR_E maximum is that :

$$\frac{d(TR_E)}{dE} = 0 \text{ , i.e. } VMP_E = 0$$

In order for our allocation rule to be satisfied at $E = E_{MSY}$, we would have to find that $\boldsymbol{b} = MC_E = 0$ – completely unreasonable, argues Gordon

In the Gordon model, we always have: $\mathbf{E_{MEY} < E_{MSY}}$

The marine biologists are not sufficiently conservationist, because they focus only on physical yields!

To drive the point home, consider the following diagram, in which $E_\infty < E_{MSY}$

From Fishing Effort Costs to Harvesting Costs

We can much greater progress by looking at harvesting costs and revenues. This will allow us to relate the consequences of “common pool” fisheries to the biomass, x.

First harvesting costs:

We are doing the same sort of thing that we do in Ec. 201/301 in going from costs and revenues with respect to inputs to costs and revenues with respect to output. The output in this case consists of harvests of fish.

So far we have:

$TC_E = \boldsymbol{b}.E$

But

$h = qEx$

$\therefore\ E = h/qx$; $\boldsymbol{b}.E = \boldsymbol{b}.(h/qx)$

We now have an expression for Total Harvesting Costs:

$C(h,x) = \boldsymbol{b}.(h/qx)$

To get Average (unit) Harvesting Costs divide through by h, and we have:

$$c(x) = \frac{b}{qx}$$

Marine biologists refer to qx as the Catch Per Unit of Effort (CPUE) – it is like the average product of E

The consequences for c(x) of decreasing biomass size:

The smaller is x the larger is c(x). Note the following:

$$\lim_{x \to 0} c(x) = \infty$$

Total Sustainable Revenue from fish harvests (TR_S):

We have, from the Schaefer model: $h_s = F(x)$

So $TR_S = \boldsymbol{p}.F(x)$

<u>Total Cost of Harvesting the Sustainable Harvest (Yield)</u>

We have: $C(h,x) = \boldsymbol{b}.(h/qx)$

We also have: $h_s = F(x)$

But $F(x) = rx[1 - x/G]$

Hence:

$$C(F(x), x) = (\boldsymbol{b}/qx).\ rx[1 - x/G]$$

$$= (\boldsymbol{b}r/q).\ [1 - x/G]$$

Thus: $C(F(x), x)$ is:

1. a linear function of x
2. decreasing in x {when $x = G$, $C(F(x), x) = 0$}

see diagram

This shows clearly the resource consequences of a "common pool" fishery.

Corresponding to E_{MEY} there is x_{MEY}; and corresponding to E_{∞} there is x_{∞}

Obviously $x_{\infty} < x_{MEY}$

Hence, we can now see that, if MEY is optimal from society's point of view, then a "common pool" fishery leads to overexploitation of the resource.

Note that this would be true, EVEN IF $\mathbf{x_{\infty} > x_{MSY}}$.

Looking forward. Suppose that we have $x = x_{\infty}$. The goal is to be at MEY. It is not simply a matter of reducing E from E_{∞} to E_{MEY}. The resource has to be rebuilt from x_{∞} to x_{MEY}. If the resource is slow growing, this could take years and years.

<u>The Perspective of the Individual Fisher</u>

For the individual fisher we have, in terms of harvest revenue and costs:

$$TR = p.h$$

$$TC = h.\frac{b}{q\bar{\bar{x}}}$$

$\bar{\bar{x}}$. The individual fisher regards the biomass as virtually fixed – reasons for.

Assume that the individual fisher is a profit maximizer. Then the fisher will attempt to produce up to the point that MC = MR.

$$MR = \frac{d(ph)}{dh} = p$$

$$MC = \frac{d(h\{b/q\bar{\bar{x}}\})}{dh} = \frac{b}{q\bar{\bar{x}}}$$

If $p > \frac{b}{q\bar{\bar{x}}}$, then the fisher will attempt to increase h.

Expansion of the fishery will continue until: $p = \frac{b}{q\bar{\bar{x}}}$

The individual fisher will have only a very small impact on x, the consequences of which he/she will share with all other fishers – **Resource Externality.**

When ALL fishers attempt to increase their exploitation of the resource, x will decline.

The overexploitation of the resource does not come about because of irrational behaviour on the fishers. On the contrary, they are acting like rational profit maximizing competitive firms.

The Consequences of Reduced Harvesting Costs in a "Common Pool" Fishery

The decline in costs may come about through falling ***b***, or because of technological improvements, reflected in ***q.***

See diagram. The falling harvesting costs will make a bad situation worse – another perverse outcome of "common pool" fisheries.

A Comment on International Fisheries

The Gordon-Schaefer model of a completely unregulated fishery is still very applicable to international fisheries – High Seas fisheries.

-the case of the Bering Seas pollock fishery

Both Americans and Russians have established EEZs in the region. There is a High Seas region in the middle not covered by the EEZs – the “Donut Hole”

In the 1980s and early ‘90s, pollock resources in the “Donut Hole” were plundered.

A Significant Limitation to the Gordon-Schaefer Model

The model predicts that a true open access fishery is never in danger of being driven to extinction.

We have from the model:

$h = qE^{\alpha}x^{\beta}$; $\alpha = \beta = 1$

consequence:

$$c(x) = \frac{b}{qx}$$

$$\lim_{x \to 0} c(x) = \infty$$

There is an effective economic brake on resource exploitation.

Recall that an underlying assumption of the model is that the fish are always uniformly distributed in the relevant body of water.

Some fish species, however, are characterized by intense schooling, e.g. herring, anchovies.

In such cases, $\beta \neq 1$. Rather $\beta < 1$, or even $\beta << 1$.

Take the extreme case in which $\beta = 0$. Then:

$c(x) = \frac{b}{qx^{0}}$; which we should properly re-express as:

$$c = \frac{b}{qx^{0}}$$

unit harvesting costs cease to be a function of x (so long as x>0).

The harvesting costs do not increase as **x** declines. The economic brake does not work.

The example of Norwegian Spring Spawning Herring.

From Pure Open Access to Regulated Open Access

The Gordon-Schaefer model is a model of what we shall now refer to as **Pure Open Access**. There are no property rights to the resource, whatsoever, there are no regulations on the fishery, national or international –the perfect "common pool" fishery case.

Regulated Open Access is the case in which there is intervention by government – at the national or international level (implying in turn that there maybe public property rights to the resource) – in the form of global controls over the season to season harvests. An example is provided by Total Allowable Catches (TACs). There are, however, no limits on the fleet size. The vessel owners have open access to the TAC.

The limited season to season harvest (TAC) now becomes the "common pool". If human and produced capital used in the fishery was perfectly "malleable", there might not be a serious problem. This is almost never the case .We do find in virtually all fisheries seasonal fixed costs – costs that cannot be escaped, once the vessels are committed to the fishery.

The consequence then of the TAC as a “common pool” is economic waste primarily, but not entirely, through the build up of redundant produced (and human) capital in the fishery.

A simple example:

In a given fishery the annual TAC = 1,000 tonnes

The TAC can be taken by **1** vessel operating over a 200 day season.

Ex-vessel price of the fish - $200 per tonne

We start off with the fleet consisting of **1** vessel – the minimum fleet size

Vessel annual costs, all reflecting true opportunity costs:

Fixed costs $20,000

Variable
costs $500 per fishing day

Vessel costs for a 200 day season

Fixed costs $20,000

Variable costs 100,000

Total Costs $120,000

Gross Revenue $200 x 1,0000 tonnes = $200,000

Therefore the vessel's economic profits are:

$200,000 - $120,000 = $80,000

Now a second identical vessel is attracted to the fishery by the positive economic profits.

The seasonal costs and revenue is as follows:

With two vessels in the fleet, rather than one, the season length is reduced from 200 to 100 days.

Annual Fleet Costs

Vessel 1

Fixed costs $20,000

Operating costs 50,000

Vessel 2

Fixed costs	20,000
Operating costs	<u>50,000</u>

Total Fleet Costs	<u>$140,000</u>

Fleet economic profits = $200,000 – 140,000 = $60,000

Economic profits reduced by the second and redundant vessel into the fleet

If we continue to assume that the fishing industry is perfectly competitive, we can say that, under Regulated Open Access, the fleet will expand up to the point that economic profits are reduced to zero. The Zero Profit Theorem once again.

As under Pure Open Access, this will result in resource rent dissipation.

The difference between the minimum costs of harvesting the sustainable yield, and the actual costs of harvesting the sustainable yield.

-see diagram.

In fact the dissipation of resource rent can be worse than under Pure Open Access. Under Pure Open Access there are no government administrative costs – by definition. Under Regulated Open Access, there are government administrative costs. When the industry is in equilibrium, the true resource rent could be *negative*. There are examples of national fisheries that are almost certainly making a negative contribution to the country's GDP.

This type of fishery is often referred to as an "Olympics style" fishery. He/she who wins the race gets the fish – the race for the fish.

The 1982 Pearse Royal Commission report on B.C. fisheries. The problems identified by Pearse have not yet been fully eliminated.

Other Sources of Economic Waste in Regulated Open Access Fisheries

1. "Crowding" – leading to destruction of gear

2. Excessive investment in vessels and gear, e.g. super powerful engines – "capital stuffing"

3. Short seasons – e.g. B.C. Pacific halibut fishery: maximum season length – 250 days per year. At one point, season down to 6 days per year. Leads to:

    a. poor handling of fish on the vessels
    b. risk to fishers
    c. processing sector inefficiencies due to glut/famine cycle.

Link Between Regulated Open Access(ROA) and Pure Open Access (POA)

In our discussion of ROA, we have assumed that the resource managers exercise complete and effective control over the season by season harvests through TACs, or equivalent. **BUT**:

1. Large fleet size makes control of harvests difficult – chronic TAC “overages”

2. Resource manages operate in a world of uncertainty. Difficult to determine optimal TAC accurately. Chronically unsatisfied vessel owners will pressure resource managers to implement liberal TACs – often use political influence. If the vessel owners succeed, the liberal TACs may prove in retrospect to have been dangerously high.

<u>Valid Conclusions Arising from the Static Economic Model of the Fishery</u>

A. MSY management criterion not defensible on economic grounds. It is based solely on physical yields.

B. Pure “common pool” Open Access fisheries lead to labour/produced capital services misallocation and to overexploitation of the resources, from society’s point of view.

C. Attempts to regulate capture fisheries by global harvest quotas alone (Regulated Open Access) lead invariably to economic waste, particularly through build up of excess fleet capacity.

<u>Limitations of the Static Economic Model of the Fishery</u>

I. Can create the illusion that restoration of the fishery resource from x_∞ (Bionomic Equilibrium) to x_{MEY} is a swift and costless undertaking.

II. Pushes the underlying biology into the background –this can be dangerous.

III. Ignores uncertainty. Uncertainty is the hallmark of real world capture fisheries management.

<u>Introduction to the Dynamic Capital-Theoretic Economic Model of the Fishery</u>

Why do we need it?

Review the key H. Scott Gordon diagram – with fishing effort, E.

The creates the impression that, to move from Bionomic Equilibrium to MEY, all we need to do is to reduce E from $E = E_\infty$ to $E = E_{MEY}$ - this is wildly misleading.

Suppose that we are at Bionomic Equilibrium, and that the Schaefer model is the correct biological model. Hence: $h = qEx$.

Suppose further that $E_{MEY} = \frac{1}{2} E_\infty$. The initial effect of cutting E from E_∞ to E_{MEY} would be reduce **h** by ½!

Consider the following diagram.

In reducing E, harvest will gradually increase as x grows from x_∞ to x_{MEY}. – reasons for.

This could be a rapid process, or a slow one.

The example of Southern Bluefin tuna, exploited by Australia, New Zealand, Japan, South Korea and others. The resource is under ineffective cooperative management. It is agreed that the resource is overexploited.

Empirical studies show that a major rebuilding of the fish stock is required, if the fishery is ever to come anywhere close to yielding MEY.

These same studies show that, even if a TAC = 0 was to be declared throughout the stock rebuilding phase, it could take 20 years to reach the desired stock size.

The rebuilding of a fish stock means that costs must be incurred today, in the hope of an uncertain payoff in the future.

Obviously, we are being presented with a resource investment problem.

This fact was recognized by H. Scott Gordon - 1956 –quote.

The reason that he went no further than his static model was because this was the best he could do with the mathematical tools available to him at the time.

<u>A Dynamic (Capital Theoretic) Version of the Gordon-Schaefer Model</u>

We continue to accept all of the explicit assumptions of the Gordon-Schaefer model that we have discussed up to this point, e.g. we assume that the demand for harvested fish and the supply of E are both perfectly elastic.

-We shall also abstract from the costs of managing the fishery - assume that such costs are zero (if we dropped this extreme assumption, it would not change the final results, but it would make the analysis somewhat messier).

Question: to what extent is it worth society's while to invest (positively or negatively) in the fishery resource? This is our Theory of Capital question.

We will focus on positive investment in the resource.

The economic effect of building up **x** will (within limits) be to increase sustainable resource rent – SRR.

This addition is assumed to go on forever and ever.

This means that we will be able to use versions of the simple investment decision rules that we discussed earlier:

C = PV,

where $PV = \frac{R}{\delta}$

$y = \delta$,

where $y = \frac{R}{C}$

Obtaining a rigorous derivation of the fisheries investment rules requires some heavy duty mathematics that we shall avoid.

If you are interested in the rigorous derivation, turn first to “Mathematical Bioeconomics and the Evolution of Modern Fisheries Economics” and Ola Flaaten. More detailed versions of the derivation are available upon request.

Now consider the following diagram.

Next consider an increase in **x** equal to 1. Roughly speaking, the Sustainable Resource Rent consequences of the increase in **x** are given by:

$$\frac{\Delta SRR}{\Delta x}.1$$

$$\lim_{\Delta x \to 0} \frac{\Delta SRR}{\Delta x} = \frac{d(SRR)}{dx}$$

Next note that: SRR = (p – c(x))F(x) {h = F(x)}
So we have:

$$\frac{d(SRR)}{dx} = \frac{d((p-c(x))F(x))}{dx} = (p-c(x))F'(x) - c'(x)F(x)$$

The addition to SRR comes from two sources:

1. Change in F(x) - (p-c(x))(F′(x))

2. Change in harvesting costs --- $c'(x)$
   but $c'(x) \leq 0$. If $c'(x) < 0$, then a minus times a minus is a positive, i.e.$\{ - c'(x)F(x) > 0\}$

<u>A Crude Example:</u>

Suppose that we begin with:

p = $1,000 per tonne

c(x) = $750 per tonne

F(x) = 10,000 tonnes per period

SRR per period = ($1,000 - $750)10,000 = $2,500,000

A marginal investment in **x** is made with the consequence that:

i. F(x) = 12,000 per period –an increase of 2,000 tonnes

ii. c(x) = $725 per tonne - a fall of $25 per tonne

(no change in p)

We now have:

SRR per period = ($1,000 - $725)12,000 = $3,300,000- an increase of $800,000

We can argue that, of the increase of $800,000 in SRR per period, $500,000 can be attributed to the increase in F(x) - 2000 {($1,000 - $750)2,000}, i.e. what the increase in SRR would be, if unit harvesting costs remained unchanged at $750.

The remaining increase in SRR, $300,000, we attribute to the fall in c(x)

Now back to the equations:

PV of an addition to SRR:

$$PV = \frac{\{(p - c(x))F'(x) - c'(x)F(x)\}}{\delta}$$

Next, the cost of an incremental investment in **x:**

In order for **x** to be increased, the harvest, **h**, must be reduced, thereby reducing current resource rent (in other than exceptional circumstances).

Denote resource rent at any point in time as: π

π = [p –c(x)]h

$$\frac{\partial \pi}{\partial h} = [p - c(x)]$$

The Net Present Value (NPV) of a marginal investment in x can be expressed as:

$$NPV = \frac{\{(p - c(x))F'(x) - c'(x)F(x)\}}{\delta} - [p - c(x)],$$

i.e. the PV of additional SRR minus the cost of the investment

If NPV > 0, then go ahead and continue investing. If NPV < 0, you have gone too far.

The investment rule is: invest (disinvest) up to the point that NPV = 0.

We can express the investment decision rule as:

$$[p - c(x^*)] = \frac{\{(p - c(x^*))F'(x^*) - c'(x^*)F(x^*)\}}{\delta}$$

where **x*** denotes the optimal biomass level

Compare this with our basic investment decision rule:

C = PV, where $PV = \frac{R}{\delta}$

We can also express our fisheries investment rule as:

$$\frac{\{(p - c(x^*))F'(x^*) - c'(x^*)F(x^*)\}}{[p - c(x^*)]} = \delta$$

Compare this with the other version of our basic investment decision rule:

$y = \delta$, where $y = \frac{R}{C}$

We can simplify the second version of our fisheries investment decision rule, so that we have:

$$F'(x^*) - \frac{c'(x^*)F(x^*)}{(p - c(x^*))} = \delta$$

This equation is often referred to as:

The Fundamental Rule (Equation) of Renewable Resource Exploitation

We can simplify further and re-write the Fundamental Equation as:

$$F'(x^*) + \frac{\partial \pi / \partial x^*}{\partial \pi / \partial h_s} = \delta,$$

where, as before, $\mathbf{h_s}$ = F(x), and π denotes resource rent.

The second term on the L.H.S. (left hand side) of the Fundamental Equation is often referred to as the **Marginal Stock Effect**. If reflects the impact of an investment in **x** upon harvesting costs.

The L.H.S. of the Fundamental Equation is, overall, the yield on a marginal investment in the resource (**x)**, also know as the “own rate of interest”. The yield consists of two components, the impact of investment in **x** upon sustainable harvests, and the Marginal Stock Effect.

Note that, if harvesting costs were completely independent of **x** (given that **x** >0), the Fundamental Equation would reduce to:

$$F'(x^*) = \delta$$

Linking the Dynamic Model to the Static Model

Given our assumptions, the simplest way in which we can express the Fundamental Equation is as follows:

$$\frac{d(SRR)/dx^*}{[p - c(x^*)]} = \delta$$

According to the static Gordon-Schaefer model, the optimal biomass, x_{MEY}, is that associated with maximum sustainable resource rent (SRR).
The first order condition for maximum SRR is that:

$$\frac{d(SRR)}{dx} = 0$$

Go back to the above equation. If $\frac{d(SRR)}{dx} = 0$, then

the only way in which the equation can hold, i.e. $x^* = x_{MEY}$, is if $\delta = 0$.

We thus conclude that the static Gordon-Schaefer model assumes implicitly that δ **= 0!**

If $\delta > 0$, then it is not worth society's while to invest in **x** all the way up to x_{MEY}

Next Bionomic Equilibrium:

Go back to our simplest version of the Fundamental Equation and re-express it as:

$$\frac{d(SRR)/dx^*}{\delta} = [p - c(x^*)]$$

At Bionomic Equilibrium, we have:

$p = c(x)$; $p - c(x) = 0$

The above equation can hold at Bionomic Equilibrium, i.e. $x^* = x_\infty$, if and only if, δ **= ∞!**

From this, we can draw two conclusions:

A. In a Pure Open Access fishery, the fishers are given the incentive to discount massively future economic returns from the fishery.

B. Even in dire circumstances, we will find that the true Social Rate of Discount, δ,is far below ∞. Hence, if we are at Bionomic Equilibrium, $x = x_\infty$, we can say, unequivocally, that the resource has been overexploited from society's point of view, i.e. $x^* >> x_\infty$.

By the way, this is the reason that we have denoted the biomass level, **x**, and the rate of fishing effort, **E**, associated with Bionomic Equilibrium as $\mathbf{x_\infty}$, and $\mathbf{E_\infty}$, respectively.

So where is x* located? We cannot say, off hand, without further investigation. If: $0 < \delta < \infty$, as is reasonable, the only thing that we can say immediately is that x* lies somewhere between x_∞ and x_{MEY}.

Surely, we can at least be certain that $x^* > x_{MSY}$. Actually, we cannot. The assurance arising from the Gordon –Schaefer model that the optimal biomass level will always exceed x_{MSY} rests upon two assumptions: (i) the Marginal Stock Effect (MSE) is positive; (ii) $\delta = 0$.

Go back to the following version of our decision rule equation:

$$F'(x^*) + \frac{\partial \pi / \partial x^*}{\partial \pi / \partial h_s} = \delta$$

The social rate of discount and the Marginal Stock Effect can be seen as pulling in opposite directions. The larger is δ, other things being equal, the **less** you will wish to invest. The larger is $\frac{\partial \pi / \partial x^*}{\partial \pi / \partial h_s}$, other things being equal, the **more** you will wish to invest.

If the MSE >0, and $\delta = 0$, as in the Gordon-Schaefer model, then in order for the investment decision rule equation to hold, we must find that $F'(x^*) < 0$. This implies that $\mathbf{x^*} > \mathbf{x_{MSY}}$ – reasons for.

If $\delta > 0$, then "all bets are off".

Note that, if the MSE = 0, then $\mathbf{x^*} \leq \mathbf{x_{MSY}}$.

<u>The case of Antarctic baleen whales – modeled by Colin Clark.</u>

Whales are a slow growing species. Does the fact that the resource is fast growing, or slow growing affect our willingness to invest in the resource? Of course.

This is not shown explicitly in our investment decision rule, but notice the following:
$F(x) = rx[1-x/G]$; $F'(x) = r[1-2x/G]$,where r is the intrinsic growth rate.

(marine biologists look to **r** as a measure of whether the species is fast growing, slow growing, or in between)

Consequently, we could re-write the investment decision rule as:

$$r\left[1-\frac{2x^*}{G}\right]+\frac{\partial\pi/\partial x^*}{\partial\pi/\partial h_s}=\delta$$

The impact of **r** upon the yield on a marginal investment in **x** (the “own rate of interest” of the resource) is then made clear.